PROGRESS REPORT NO. 3
on
SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

A Joint Project of the

Environmental Quality Laboratory
California Institute of Technology

and

Shore Processes Laboratory
Scripps Institution of Oceanography

Prepared by

Brent D. Taylor
William M. Brown
William R. Brownlie

November 1977

EQL Open File Report No. 77-8

TABLE OF CONTENTS

Section		Page
I.	INTRODUCTION	1
II.	PROJECT ADMINISTRATION	2
III.	SPECIAL PROJECT ACTIVITIES	3
IV.	RESEARCH WORK	4
	A. Data Compilation	4
	B. Preliminary Estimates of Regional Sediment Budget	5
	C. Detailed Studies	9
	1. Major Rivers Study	11
	2. Watershed Erosion Factors Study	12
	3. Shoreline Study	13
	4. Map Preparation	14
V.	FIGURES	15
	Figure 1 CIT/SIO Sediment Management Study Area in Southern California	16
	Figure 2 Regional Sediment Budget Factors	17
	Figure 3 General Sediment Size Classification	18
	Figure 4 Depositional Areas	19
	Figure 5 Littoral Cells in Southern California	20
VI.	APPENDICES	21
	Appendix A - Tentative Outline of CIT/SIO Sediment Management Project	22
	Appendix B - Sediment Management Newsletter Volumes 1 and 2	27
	Appendix C - Preliminary Report on Coastal Sediment Delivery by the Santa Clara River, 1928-1975	47
	Appendix D - Recent Erosion in the San Gabriel Mountains	71
	Appendix E - Preliminary Map identifying inland sediment movement control structures	

I. INTRODUCTION

The Environmental Quality Laboratory at Caltech and the Shore Processes Laboratory at Scripps Institution of Oceanography have jointly undertaken a study of regional sediment balance problems in coastal southern California (see map in Figure 1). The overall objective in this study is to define specific alternatives in sediment management that may be implemented to alleviate existing sediment imbalance problems (e.g. inland debris disposal, local shoreline erosion) and possible future problems that have not yet manifested themselves. These alternatives will be identified through a consideration of economic, legal, and institutional issues as well as an analysis of governing physical processes and engineering constraints.

The first part of this study (Phase I), which is currently under way, involves a compilation and analysis of all available data in an effort to obtain an accurate definition of the inland/coastal regional sediment balance under natural conditions, and specific quantitative effects man-made controls have on the overall natural process.

During FY77, with financial support from Los Angeles County, U. S. Geological Survey, Orange County, U. S. Army Corps of Engineers, and discretionary funding provided by a grant from the Ford Foundation, substantial progress was made at EQL and SPL in achieving the objectives of the initial Planning and Assessment Phase of the CIT/SIO Sediment Management Project. The current timetable for completion of this phase is Fall 1978.

This report briefly describes the project status including general administration, special activities, and research work as of September 1977.

II. PROJECT ADMINISTRATION

During the past year there have been continuing efforts to establish and maintain close liaison with appropriate local, state and federal agencies in an attempt to increase the technical involvement of these agencies, and to obtain financial support from all agencies that will derive substantial benefits from the CIT/SIO study.

In late 1976 the Corps of Engineers approved funding for the CIT/SIO project ($\$50^k$/yr: two years). First-year funding from COE was forwarded in June 1977.

During March 1977 a letter of agreement for technical assistance was signed with the U. S. Forest Service. Under the terms of this agreement a Masters level research hydrologist has been assigned to work 1 day/week at Caltech on project sub-studies of special importance to the Forest Service. Initially this hydrologist is working on the effect of fires on sediment yield from upland watersheds.

A new commitment of $\$10^k$/year in continuing project support has also been indicated by the Department of Navigation & Ocean Development in the State Resources Agency. This support will begin in FY78.

In June 1977 a meeting was held with Ventura County to begin negotiations for transferring funds to Caltech in support of the CIT/SIO sediment management project during FY78. These negotiations have not yet been completed.

With the new and continuing financial support anticipated for the coming year the scale of project effort can be increased somewhat. However, additional commitments by other agencies will be necessary to enable the full-scale effort planned (see Appendix A).

We are currently conducting negotiations for additional financial support with Sea Grant, U. S. Forest Service, County of San Diego, and California Resources Agency.

III. SPECIAL PROJECT ACTIVITIES

During 1976 two special project activities were undertaken--a two-day workshop, and the introduction of a newsletter to report on the CIT/SIO study and other issues pertaining to regional sediment management. Approximately 200 people attended the workshop, including representatives from 25 federal, state and local governmental agencies, 11 universities, public utilities, engineering and consulting firms, and the general public. This workshop helped to clarify research questions pertaining to regional sediment management and to promote a cooperative research effort among institutions and agencies. The general conclusion of the workshop might be stated as follows: the large population, high level of development throughout the coastal region of southern California, and diverse and intense use of local resources for industry and recreation (some 50 million user-days of shoreline recreation and 10-14 million user-days of mountain and national forest recreation per year) underline the importance of understanding the natural sediment processes, their interrelations and the correlative effects man has imposed. More thorough analyses of inter-regional management strategies are needed to help ensure that we do not contradict our own efforts in attempting to solve existing sedimentation problems, and that our actions do not produce undesirable results that may be very costly or impossible to correct in the future.

The project newsletter was initiated to build upon and continue workshop objectives, i.e. provide a vehicle for a continuing informal exchange of ideas and information among managers, engineers, and scientists involved in sedimentation problems in southern California, and to disseminate information on the CIT/SIO project. This newsletter will be published periodically as necessary to meet these objectives. More than 1000 copies of the first two newsletters, printed in November 1976 and August 1977 were distributed to managers, engineers, academic people, county, state and federal political representatives, and other interested parties. Copies of the first two newsletters are provided in Appendix B.

IV. RESEARCH WORK

Research work thus far has included data compilation: tabular and computerized data files; preliminary data analysis to obtain first-order estimates of aggregate mean annual regional sediment movements; and detailed studies focusing on natural factors affecting upland erosion, natural versus actual (with artificial controls) sediment deliveries to the shoreline between 1925 and 1975 by nine major rivers in the study area; and an analysis of littoral transport along the coast and historical changes in the shoreline and local beaches. Several special maps are also in preparation. These individual work efforts are described in the following sections.

A. DATA COMPILATION

During 1976 and 1977 the following data have been compiled:

1. Streamflow data: Daily mean and annual peak flows for several hundred large and small streams throughout the study area. A master list of all available streamflow records has been obtained from the California Department of Water Resources and has been entered onto magnetic tape for ready computer access. The list encompasses 852 stations in the study area at which streamflow data were collected. Some 450 of these stations have been operated by the U.S. Geological Survey, and the master computer files of the USGS have been accessed to transfer useful data to Caltech.
2. Sediment-transport data: Daily mean discharges and individual sample data for both suspended-sediment and bedload transport. These USGS data are derived from 32 stations in the study area, of which
   - a) 20 stations have from 1 to 9 years of continuous records;
   - b) 19 stations, primarily on upland drainages in the Santa Clara River basin, have intermittent records;
   - c) 2 stations (the Los Angeles and San Gabriel Rivers near their mouths) were established in late 1975 specifically for the CIT/SIO project;
   - d) 10 stations have 1 to 2 years of bedload data;
   - e) 11 of the 20 stations above are on the mainstem of rivers near their points of discharge to the ocean.

   In all, 110 station-years of daily suspended-sediment discharge data are available from the USGS. These data have been obtained in punched-card format and have been entered onto magnetic tape and disk. Data on the particle-size distribution of suspended sediment and bedload are being entered onto computer cards for subsequent entry onto tape or disk.

3. Geologic data: An extensive set of regional and sub-regional geologic maps.

4. Aerial imagery: An inventory of existing imagery shows that more than 100,000 images are available for the study area from the USGS, National Aeronautics and Space Administration, U.S. Forest Service, and other public and private sources. A compilation of flight lines, image centers, and image scales for USGS, NASA, NOAA, and USFS data is now on file at Caltech. Additional aerial photograhy is available at Scripps. A precision scanning stereoscope has been loaned to the project by the USGS for inspection and analysis of stereoimagery.

5. Beach and offshore sediment-size data: Size-distribution data for 95 samples in Ventura, Los Angeles, Orange, Santa Barbara, and San Diego Counties by the Los Angeles District, Corps of Engineers, for the period 1967-69. More than 350 additional sand samples at various locations along the coast of the study area were obtained and analyzed by the Corps from 1963 to 1966.

6. Fire history data: Acreage burned, locations and dates of forest and brush fires that have occurred in the study area during the past 65+ years. These data have been collected from county agencies and the U.S. Forest Service.

7. Sand and gravel mining data: Location, quantity, and size distribution of sand and gravel mined in the study area. (These data will be used to assess the magnitude of sediment usage and artificial movements effected by human activity. A detailed knowledge of demands for sand and gravel will aid in weighing alternatives for disposal of material that must be excavated from flood-control and debris basins.)

B. PRELIMINARY ESTIMATES OF REGIONAL SEDIMENT BUDGET

Using data compiled thus far, some preliminary estimates have been obtained for regional sediment budget factors characterized schematically in Figure 2.

Debris accumulation and sediment discharge data from Ventura, Los Angeles, Riverside, Orange, and San Diego Counties were used to obtain estimates of mean annual surface erosion rates. The results indicate that to a first approximation, there are three characteristically different types of land forms in the study area. Mountainous areas, characterized by steep slopes, well-defined features and abrupt vertical reliefs of thousands of meters are one type. This land form is primarily the result of two extremely active morphologic processes; tectonic faulting, and hydraulic erosion. For this land type longer-term mean annual erosion rates of from 0.6-2.5 mm/yr have been measured.

The second land type is hill areas. These areas are geologically mature and have well-rounded features with moderate vertical reliefs of several hundred meters. Limited available data suggest erosion rates in hill areas of approximately 0.2-0.4 mm/yr.

The third type, plains areas, is noted for its smooth features, very gradual slopes and low relief (tens of meters). Although this land type does yield sediment, the amount is small ($\sim$ 0.01 mm/yr). Plains areas serve primarily as intermediate depositional zones between mountain and hill areas, and the shoreline. (In some areas, of course, the mountain and hill areas drain directly to the shoreline.) Hence, there is generally a net long-term aggradation on plains areas.

Based on these values of mean annual erosion rates, in conjunction with a generalized land form classification of the study area, preliminary estimates were made of mean annual sediment erosion from mountain, hill and plains areas, as follows

Land Form Areas		
Mountains	8,800	km^2
Hills	8,600	
Plains	12,600	
	30,000	km^2

Land Form Erosion (Mean Annual)

	Unit Rate	Aggregate (all sizes)
Mountains	1. mm/yr	8.8 Million m^3/yr
Hills	0.3	2.6
Plains	0.01	0.1
		11.5 Million m^3/yr

Using the sediment size classification and estimates of particle size distribution shown in Figure 3, the following estimates have been computed for sand (0.064 - 2.0 mm) production.

Sand Production (Mean Annual)

Mountains	3.1 Million m^3/yr
Hills	1.0
Plains	0.02
	4.1 Million m^3/yr

In the study area, sediment deliveries to the shoreline originate from nine major rivers and more than 80 other streams that drain coastal plains and mountain and hill areas. Based on sediment discharge and streamflow data already compiled estimates have been made of annual sand deliveries to the shoreline, as follows:

Sand Discharge to Shoreline Areas

	Estimated Annual Average*	% of Total	1969 Flood
Major Rivers	m^3		
Ventura	100,000	10%	
Santa Clara	500,000	51	10,100,000
Los Angeles	10,000	1	
San Gabriel	10,000	1	
Santa Ana	75,000	8	2,200,000
San Luis Rey	10,000	1	
Santa Margarita	25,000	3	
San Diego	10,000	1	
Tijuana	5,000		

Sand Discharge to Shoreline Area (continued)

	Estimated Annual Average*	% of Total	1969 Flood
Smaller Streams			
San Juan Creek	40,000	4	1,150,000
Other Streams	200,000	20	
Total	985,000	100%	

*Based on 1951-74 period of record. For these estimates it was assumed that sand transport is equal to 30% of total sediment transport.

These estimates suggest that at present approximately 1/4 of the sand produced by land surface erosion is eventually delivered to the shoreline area.

The above table also gives single-year (1969) estimates on three streams. These data indicate large variations in annual values of shoreline sand delivery. Data in the following table, collected by the USGS on the Santa Clara River which is relatively uncontrolled further illustrates this annual variation.

Variation in Suspended Sediment Transport (all sizes) by Santa Clara River Near Mouth

Water Year	Annual Transport Millions m^3	Equivalent Average Erosion Rate mm/yr
1968	0.043	0.01
1969	29.0	6.9
1970	0.38	0.090
1971	1.4	0.33
1972	0.27	0.064
1973	2.4	0.59

These variations (nearly three orders of magnitude) in annual sand supply to the shoreline suggest that under natural conditions there are significant year-to-year fluctuations in shoreline configuration and beaches near major river mouths. The amplitude and down-shore movement of these natural fluctuations have not yet been determined.

Preliminary data also indicate that during the past 30 years, more than 300 million cubic meters of sedimentary material have been mined by sand and gravel producers, some 30 million m^3 of sediment has been removed and relocated from reservoirs and debris basins, and more than 85 million m^3 of sand-sized sediment have been artificially placed on beaches in southern California for widening and nourishment through coastal dredging operations. Additional dredge-spoil sediment has been used for land fill or disposed of in offshore areas.

These data suggest that the scale of man-induced sediment movements is of the same order of magnitude (1-10 million m^3/yr) as natural sediment movements, and perhaps most significantly man's activities (artificial nourishment) along the shoreline have had a first-order effect on beach stability and configuration.

C. DETAILED STUDIES

In the detailed studies now under way inland areas have been classified as being either geologically-recent erosional or depositional areas. Generally mountains and hills are erosional surfaces while river valleys and coastal flood plains are depositional. Figure 4 is a photo reduced copy of a preliminary 1:250,000-scale working map constructed to define erosional and depositional surfaces in the study area.

The boundary between inland erosional and depositional landforms provides a natural boundary through which to define sediment flux. A second such natural boundary is the shoreline. For some areas these two boundaries essentially coincide, e.g. Malibu Creek.

In each case, with the erosional/depositional boundary and the inland/ocean boundary, distributed sediment flux is not uniform. Rather, it is concentrated at discrete locations along the boundary called stream channels. There are, however, occasional natural lateral migrations of these concentration points along the boundary. Sediment flux at each concentration point is the result of processes acting on the inland area of higher elevation which contributes surface runoff to this point. This area is called the catchment, watershed or drainage basin above the concentration point.

In defining the sediment flux at a concentration point on either of the two boundaries two characteristically different approaches are available. The first might be thought of as a black-box approach wherein the output function, streamflow, and sediment discharge are measured over a period of years. The time series of sediment flux identified by these data can then be correlated with time series at other concentration points and the sediment flux across the boundary defined as a function of time and location.

An alternate approach seeks to quantify watershed characteristics and climatic conditions important in sediment-yielding geomorphic processes. With this quantative information and a relationship between these factors and watershed hydrology, basin output (streamflow and sediment discharge) can be predicted.

Each of the two approaches has comparative advantages and disadvantages. Because of the extremely complex processes operative in a natural watershed it is very difficult to develop an accurate predictive model based on watershed characteristics and climatic conditions as with the second approach. However, often input data for such a model are more readily obtained than the longer-term sediment discharge and streamflow data required in the first approach. Also output data alone do not enable a detailed understanding of a watershed process or the effect of changes in watershed conditions. Output data though, when available do in general enable more accurate estimates of watershed behavior.

In the CIT/SIO study area there are watersheds draining through the natural boundaries defined above which range from less than 0.1 km^2 to more than 10^3 km^2, watersheds wherein streamflow and sediment discharge have been measured and many where there have been virtually no output measurements. In the CIT/SIO study area there is a significant number of watersheds without output measurements which drain directly to the shoreline.

Therefore in order to treat all of the important watersheds which transport sediment through the boundaries defined above, each of the two approaches must be employed. The advantages of being forced to employ both approaches are that overall understanding of watershed sediment transport processes should be enhanced and a greater accuracy may be realized through a comparison of results from two independent techniques.

We have two studies currently under way in which the strategies employed are representative of the two different approaches described above.

1. Major Rivers Study

On nine major rivers draining to the shoreline in the study area, streamflow and limited sediment discharge data are available. These rivers include the Ventura, Santa Clara, Los Angeles, San Gabriel, Santa Ana, Santa Margarita, San Luis Rey, San Diego, and the Tijuana which has a large part of its drainage in Mexico. The objective in this sub-study is to quantify the beach-sized sediment delivery to the shoreline that took place on these rivers each year from 1925-75 and also to accurately estimate the respective sediment deliveries that would have taken place under natural conditions without the advent of flood control and water conservation facilities during this period. 1925-75 was chosen as the study period because during this time the significant human development took place in southern California and most of the available historical streamflow/sediment discharge data were collected. Individual data records on the nine rivers vary from a few years to more than 70 years.

Analyses on seven of the nine rivers are in different stages of completion. Preliminary reports on the Ventura River and the Santa Clara River are provided in Appendices B (Newsletter #2) and C, respectively.

It is anticipated that the major rivers study will be completed by Spring of 1978.

2. Watershed Erosion

In order to predict sediment deliveries from ungaged watershed areas it is necessary to 1) identify the parameters that are casually important in the processes of erosion and transport, and 2) quantitatively relate these parameters to watershed sediment production.

Data in the CIT/SIO study area available for this analysis include:

1. Short and longer-term sediment accumulation data for more than 100 reservoirs and debris basins distributed non-uniformly throughout the study area.
2. Surficial geology maps of selected areas within the region (parent material, slope stability).
3. USGS Topographic Maps
4. Precipitation data for several hundred rainfall stations distributed non-uniformly throughout the study area with records varying from a few years to more than 100 years.
5. Tectonic and seismic maps which define local faulting and levels of earthquake activitity. (These maps may help to identify the effects of tectonic activitity on watershed morphology and the structural

condition of the parent material; also the relative effect of present seismic activity in effecting mass movements on a watershed.)

One can conceptually identify four general factors which are primarily responsible for watershed sediment yield. They are:

1. Topography
2. Vegetation (including fire history)
3. Surficial Geology
4. Precipitation

The first step in the current analysis has been to study a cluster of watersheds wherein there is a large body of field data, but some homogenity in the four general factors affecting sediment yield such that there is a reduced number of parameters which vary significantly among the watersheds. This limited variation facilitates an initial identification of some of the parameters which affect watershed sediment delivery.

The second step in this study will be to analyze the larger data set available for the entire study area.

The relatively large body of data available on watersheds in the San Gabriel Mountains and the general similarity of these watersheds led to this area being chosen for the initial step in the detailed watershed analysis. As part of this sub-study, a paper has been prepared (see Appendix D) on sediment production in the San Gabriel Mountains. This paper was presented at the ASCE Annual Convention in San Francisco, October 18, 1977.

3. Shoreline Studies (Scripps)

At Scripps efforts are under way to inventory and compile the large body of beach profile data collected over the past 30-50 years. Results from this effort will help to define the range of periodic changes in beach configuration and the shoreline and identify long-term changes that may be taking place along the shoreline, due to natural and man-made causes.

There is a second effort under way at Scripps to compile available longshore transport data for each of the five major littoral cells defined in the southern California region (Figure 5). Each littoral cell will then be examined in terms of its sediment budget: the input from land versus the losses to offshore basins and downcoast cells.

4. Map Preparation

As part of the data compilation and analysis, composite maps are being prepared to assist with certain types of data, and to present study results in the most useful way.

Recently the USGS agreed to publish special maps prepared as part of the CIT/SIO sediment management study in a Hydrologic Atlas Series. The first maps to be published in this series will be regional fire history maps. These maps show fire histories throughout the study area back to 1910. Decade maps, i.e. for each ten year period 1940-49, 1950-59, etc., as well as a 66-year composite map showing fire histories, are being prepared. Other maps currently in preparation include:

- map locating artificial control structures (a total of 1106) in the study area with a classification of the type of control each structure exerts on local sediment movement.
- map defining inland erosion potentials. The maps are being prepared at a scale of 1:250,000.

(See Appendix E for preliminary sample copy of project maps.)

FIGURES

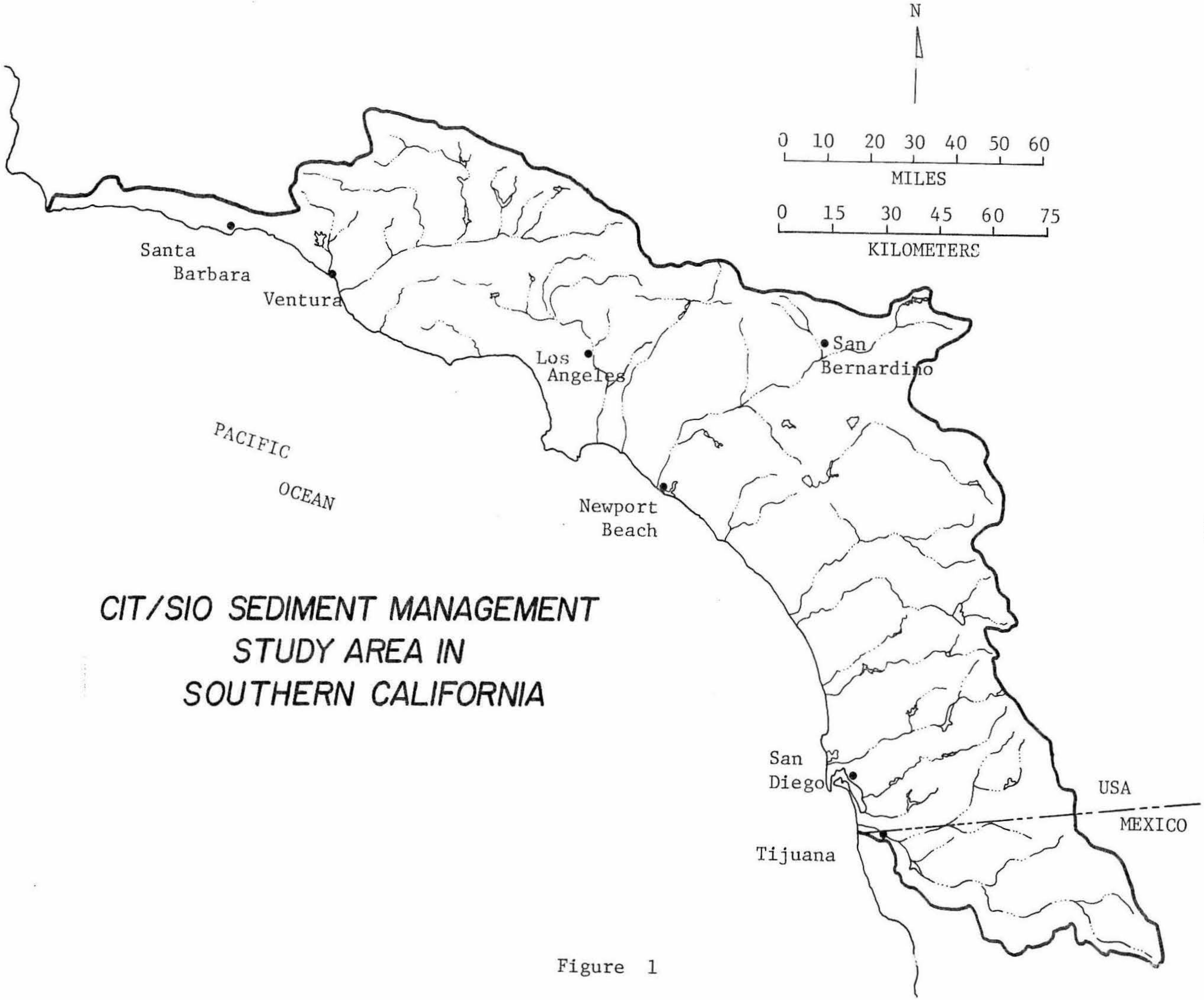

N
0 10 20 30 40 50 60
MILES
0 15 30 45 60 75
KILOMETERS
Santa Barbara
Ventura
Los Angeles
San Bernardino
PACIFIC OCEAN
Newport Beach
CIT/SIO SEDIMENT MANAGEMENT
STUDY AREA IN
SOUTHERN CALIFORNIA
San Diego
USA
MEXICO
Tijuana

Figure 1

FIGURE 2

REGIONAL SEDIMENT BUDGET FACTORS

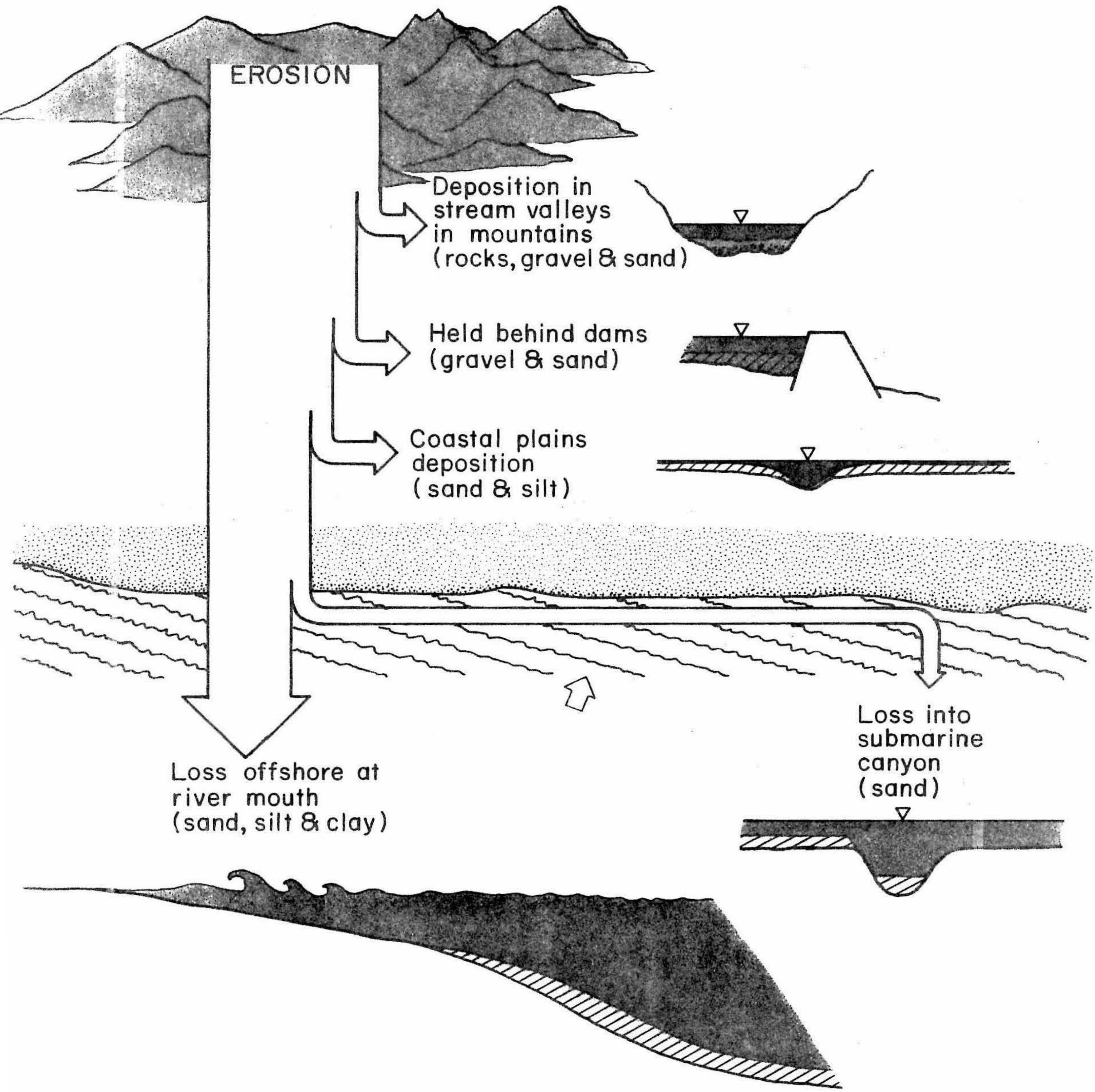
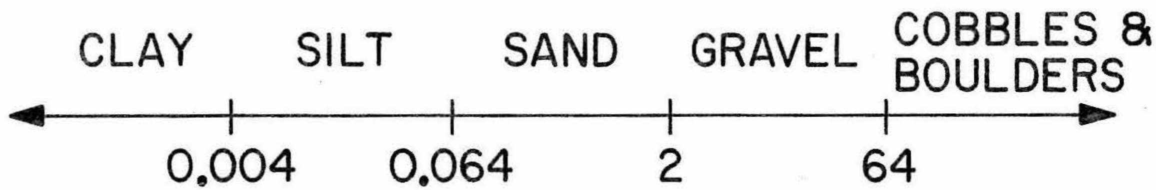


FIGURE 3

GENERAL SEDIMENT SIZE CLASSIFICATION

SIZE RANGE IN MM



PERCENTAGES FOR:

MOUNTAIN EROSION	50%	35%	15%
HILL EROSION	60%	40%	—
PLAINS EROSION	80%	20%	—

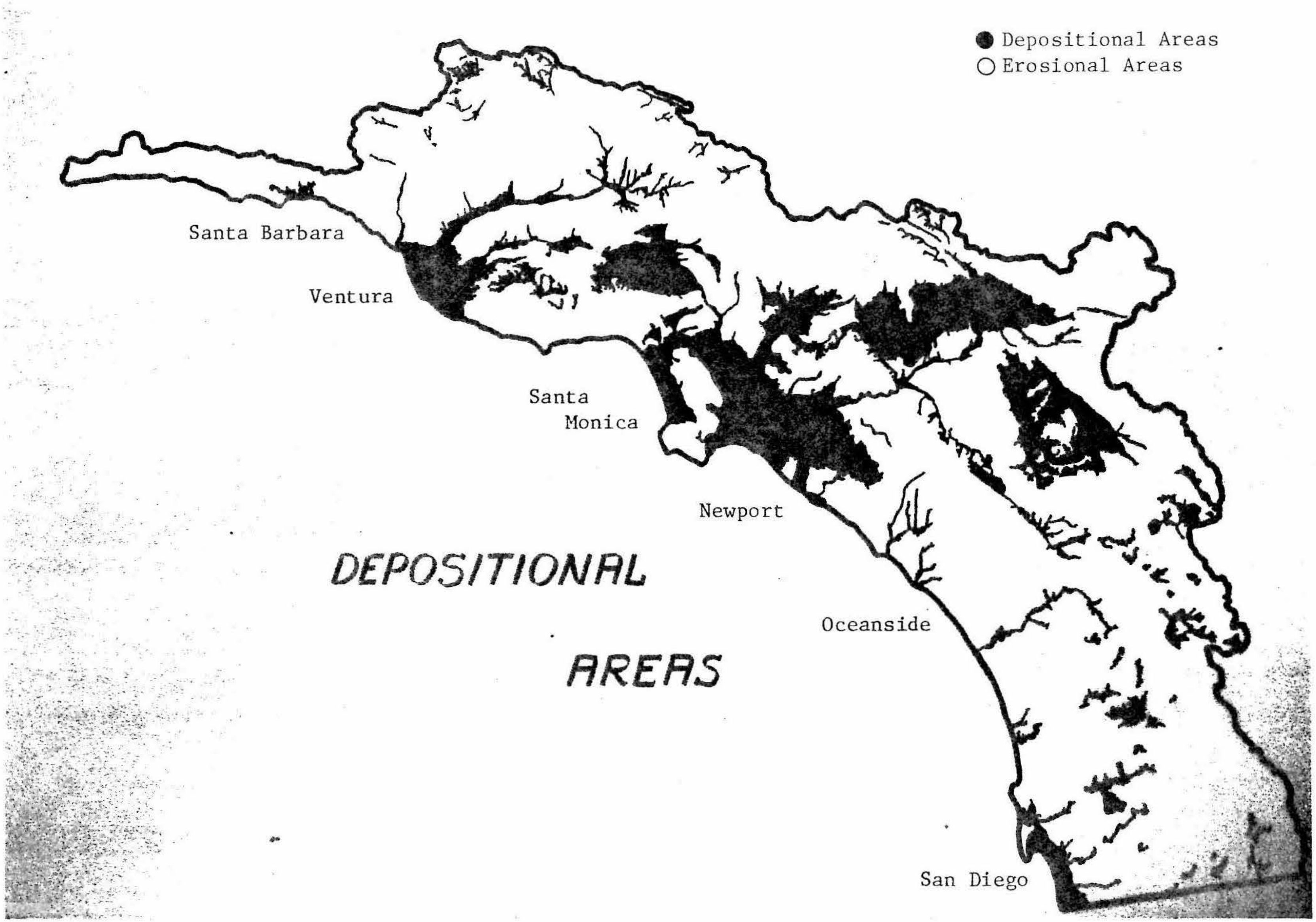


FIGURE 4

Inland depositional areas for natural sediment movements during recent geologic period in Southern California.

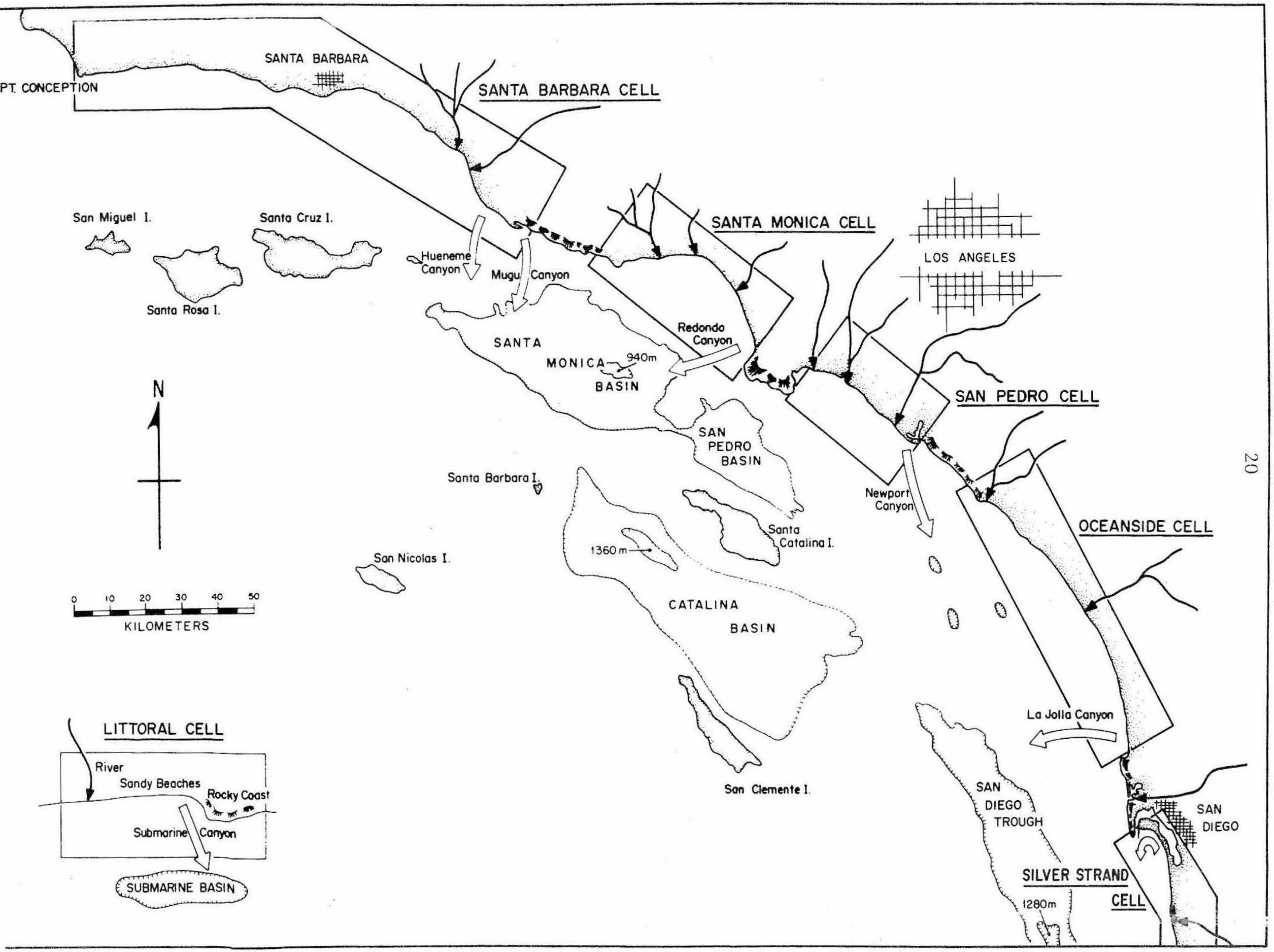


FIGURE 5. Littoral Cells in Southern California

APPENDICES

APPENDIX A
TENTATIVE
OUTLINE OF CIT/SIO SEDIMENT MANAGEMENT PROJECT
TASKS TO BE COMPLETED DURING THE PLANNING & ASSESSMENT PHASE

The primary study objectives for the initial phase of the CIT/SIO project are:

1. With available data, develop best possible estimates of annual regional sediment movements, and identify the specific effects man-made controls have had on the natural regional sediment budget.
2. Identify additional field data needs to adequately define regional sedimentation processes and overall sediment budget. (Additional field measurements will begin as soon as feasible after recognition of specific needs, e.g. USGS began ongoing sediment discharge measurements at the mouths of the Los Angeles and San Gabriel Rivers during the winter of 1975-76 as part of this project.)

In order to achieve these objectives a specific work program has been developed and is under way. This program outlined in detail in the following section is based on:

1. An inventory of available field data.
2. Compilation of pertinent data in optimal formal, e.g. computerized digital files, maps, etc.
3. Analyses of field data.

The planning and assessment phase is scheduled for completion in Fall, 1978, when a formal report will be prepared and published describing all study results obtained thus far.

Following are outlines of sub-tasks to be undertaken at EQL and SPL during the initial project phase, work flow and project outputs.

CIT/SIO TECHNICAL WORK OUTLINE

AT CALTECH:

A. Prepare preliminary (first-order) estimates of i) mean annual sediment erosion and shoreline sand deliveries to compare with available estimates of littoral sand transport and losses along the shoreline, and ii) artificial sediment movements, e.g. dredging, to ascertain general scales of natural and artificial components in current regional sediment budget.
   1. Using general relation between streamflow and sediment discharge defined by existing data, estimate average annual sand deliveries to shoreline areas by coastal streams.
   2. Using generalized erosion rates for different land types based on available debris production data, estimate total average annual erosion from mountain areas, hills, and coastal plains.

B. Prepare geographically-detailed, best-possible estimates of annual and mean annual inland sediment erosion and deposition, and shoreline sediment deliveries during the past 50 years (period of important human development) under actual conditions, and natural conditions that would have occurred without human development.

1. Define sediment transport characteristics of coastal streams flowing over alluvial plains using available streamflow and sediment discharge data.

    a. Define streamflow/sediment transport relations for coastal streams and rivers.
    b. Construct 50-year (1925-75) time-series of annual streamflow parameters, e.g. peak discharge, annual runoff, which may be used to estimate annual sediment transport, for 1) historical (actual) conditions, and 2) hypothetical uncontrolled (natural) conditions.
    c. Identify historical changes in stream drainage networks including location of stream mouths along the shoreline.

2. Identify sediment production characteristics of upland watersheds, for which sediment discharge data are not available.

    a. Identify watershed precipitation parameters which correlate best with sediment production.
    b. Identify topographic parameters which best characterize topographically-related sediment erosion potentials.
    c. Identify geologic parameters which best characterize related sediment erosion potentials, e.g. recent depositional/erosional areas, lithology of erosional areas.
    d. Define the quantitative effects of fire on annual sediment production on upland watersheds.
    e. Prepare best-possible estimates of inland sediment production (volume and size-distribution) from erosional areas throughout the region.

C. Prepare a detailed geographic definition of artificial sediment movements during the past 75+ years.

1. Compile data on reservoirs, debris basins, check dams, and channel cleanouts (locations, dates, amounts, sediment sizes and disposal/usage sites).

2. Compile data on historical sand and gravel mining operations (locations, dates, amounts, material sizes, general usage areas).

3. Compile data on coastal dredging, sand bypass, and artificial beach nourishment (locations, dates, amounts and sediment sizes).

AT SCRIPPS:

A. Inventory and Classification

1. Reconnaissance of shoreline from Point Conception to Mexican border to determine shoreline type (exposed beaches, pocket beaches, rocky shoreline, artificially modified shoreline).

2. Type and composition of littoral material (sand, gravel, rocky shoreline, etc.).

3. Compile beach profiles for coastal segment between Point Conception and Mexican border from various sources (Corps of Engineers, State of California, SIO/SPL, local agencies, etc.).

B. Mapping

1. Prepare a base map showing the shoreline type in the study area and other pertinent information.

2. Prepare in tabular and graphic form all sedimentological information for beaches in study area.

C. Analysis

Establish best possible sediment budget for littoral cells in the study area on the basis of existing data.

JOINT CALTECH/SCRIPPS:

A. Identify additional field data needed for a comprehensive and accurate definition of regional sedimentation processes and sediment budget items.

B. Prepare final report on Planning and Assessment Phase.

CIT/SIO PROJECT OUTPUT

MAPS:

1. 1:250,000 scale maps of regional fire histories by decade and composite for past 65+ years.
2. 1:250,000 scale map of inland geomorphic units as defined by erosion potential, topography, and geology.
3. 1:250,000 scale map identifying man-made sediment movement controls by watershed and larger drainage basin, with delineation of type and degree of control.
4. 1:250,000 scale map identifying historical man-induced sediment movements (dredging, reservoir cleanouts, sand & gravel mining, sand bypassing, artificial beach nourishments).

5. 1:250,000 scale map of historical river patterns (avulsions and flood plain spreading in lower reach, and changes in location of mouth along the shoreline).

DATA FILE OUTPUT:

Data output will consist of an identification of specific data files available, their original source, form of the data, e.g. tabular, computer cards, tapes, etc., a general description of data quality, and recommended procedure for obtaining a copy of the data set. This data output will be included with map and/or publication output as appropriate.

PUBLICATIONS:

1. Newsletters: Fall 1976, Summer 1977.
2. Papers: "Recent Erosion in the San Gabriel Mountains," by W. M. Brown and B. D. Taylor, presented at ASCE Conference, San Francisco, October 1977.

SPECIAL ACTIVITIES:

1. Workshop on "Sediment Management for Southern California Mountains, Coastal Plains and Shoreline," March 15-16, 1976.

PRELIMINARY

GENERAL OUTLINE FOR CIT/SIO PROJECT:
PHASES II, III, & IV (concurrent)

CALTECH AND SCRIPPS:

Field Study (Phase II)

A. Obtain critical data necessary to complete quantification of regional sedimentation budget under existing conditions (uncertain completion, partially begun Winter 75-76):

1. Inland sediment production
2. Transport of sediment through the natural and flood control systems to the ocean
3. Sediment transport in the littoral zone
4. Shoreline and beach changes; time scales of accretion and depletion
5. Sand losses to deep water.

B. Obtain additional data necessary to accurately define "baseline" situation (natural conditions of inland sediment production and transport in streams, and beach processes without man's interference).

Analysis (Phase III)

Conceptual design and evaluation of alternative inland and shoreline sediment management systems (Fall 79).

Policy Studies (Phase IV)

Consideration of institutional, legal and economic questions pertaining to alternative future sediment control strategies (Fall 1981).

Number 1
Fall 1976

Southern California Sediment Management Newsletter

Environmental Quality Laboratory, California Institute of Technology, Pasadena, California
Shore Processes Laboratory, Scripps Institution of Oceanography, La Jolla, California

Caltech and Scripps Launch Regional Sediment Study

Natural drainage of coastal mountains carries with it sediments that are deposited downstream, forming alluvial fans and nourishing beaches. The beaches, in turn, are subjected to the action of ocean waves and currents that create littoral transport and reshape the coastline. These processes are dynamic, and any equilibrium is usually temporary, even though the time of significant change may be very long.

The natural sedimentation processes on coastal and mountain watersheds and along the shoreline have been disturbed by man in many communities. In general, two types of activities have altered natural sediment movements. First, land-management and flood-control works reduce inland sediment production and thereby interfere with the natural supply of sand to nourish the beaches. Second, the building and maintenance of shoreline and nearshore engineering works, such as harbors, jetties, groins, and breakwaters, perturb the littoral processes. These factors in combination can have far-reaching, long-term effects on the coastline.

The Environmental Quality Laboratory at the California Institute of Technology and the Shore Processes Laboratory at Scripps Institution of Oceanography have initiated a joint applied research project to examine the magnitude of regional sediment balance problems and to define future coastal sediment management alternatives.

The CIT/SIO study will focus on the Southern California coastal region (see accompanying map) which comprises the California shoreline and coastal drainages between Pt. Conception and the Mexican border, though many of the results will be applicable to coastal regions elsewhere. This coastal section in Southern California has more than 450 kilometers of shoreline, a population of 12 million

(continued on page 2)

Introducing Newsletter No. 1

Meet our newest publication — *Southern California Sediment Management Newsletter*. It will keep you up to date on the activities and progress of the joint Caltech/Scripps Sediment Management Project, bring you selected news items from the various agencies, and provide you with announcements of upcoming events and publications. Our hope is to foster a more comprehensive view of the overall sediment problems of the heavily-developed coastal plain and shoreline of Southern California and to generate a useful exchange of ideas among all those people who are concerned with the problems. So far, the people who worry about floods and the excesses of sediment that pour out from the mountains have not been too well acquainted with the people who look after the long-range stability of the beaches.

The size and frequency of the newsletter will be flexible at the start, but we plan to issue it at least quarterly. We solicit your contributions; they should be brief and timely. Remember, we don't want this to be a technical journal but rather an easy-to-read semi-technical publication to highlight what is going on. We will accept letters to the editor, also.

The editor of the newsletter is Suzanne Sayer, of the staff at EQL. The closing date for the next issue will be January 31, 1977. Let us have all your good ideas and we'll make this a lively forum for the sediment people in our area.

The project logo was designed to identify all three phases of coastal sedimentation — erosion of sediment from upland watersheds, sediment transport by streams and rivers that drain to the shoreline, and littoral transport along the shoreline, as characterized by the breaking wave. The sun symbolizes the direct influence of the semi-arid climate on the sedimentary process of this region. This logo will serve as the identifying symbol for the CIT/SIO Sediment Management Project, and will appear on all project publications. We hope you like it!

(continued from first page)

people, and embraces some 29,000 square kilometers of inland drainage. More than 80 coastal streams and nine major rivers drain to the shoreline in this area.

The primary objective in the CIT/SIO Sediment Management Project is to define future alternatives in regional sediment management that may be implemented to alleviate sediment balance problems — for example, inland debris disposal and beach stability. Natural sediment movement throughout the study area and the human effects on regional sedimentation processes will be quantitatively defined. Coastal sediment management must be based not only on a clear understanding of all of the natural geologic, hydrologic, and oceanographic processes, but also on engineering, economic, institutional, and legal constraints. Therefore, in conjunction with the project's technical efforts, detailed consideration will be given to each of these factors in evaluating alternative management strategies.

Sediment Management Workshop

In March 1976, a workshop on sediment management in Southern California was held at Caltech as an integral part of the initial phase of the CIT/SIO project. Nearly 200 representatives from 25 federal, state, and local agencies, 11 universities, and a number of private engineering firms and public utilities attended. The workshop gave an opportunity for researchers and engineers working on different aspects of regional sediment management a chance to get acquainted and to discuss inter-regional problems and processes in inland and coastal sedimentation.

In the opening talk Professor D. L. Inman, principal investigator at SIO, outlined the concept of littoral sedimentation cells along the shoreline. These cells act in part as independent units. Beach-forming sediments are introduced into a littoral cell primarily by streams and rivers that drain to the shoreline. This material is transported along shore by wave-generated currents, and eventually the beach material is lost from the shoreline — for example, down submarine canyons. Five littoral cells can be identified for coastal Southern California between Point Conception and the Mexican border, as indicated in the accompanying figure.

Inman discussed the shoreline* and emphasized the fact that although we have a qualitative model for the sedimentation balance in a coastal region, a quantitative model of this balance is not currently available. Without such a model, it is not possible to identify the overall consequences of alternative sediment-management strategies or the building of individual shoreline and inland control structures.

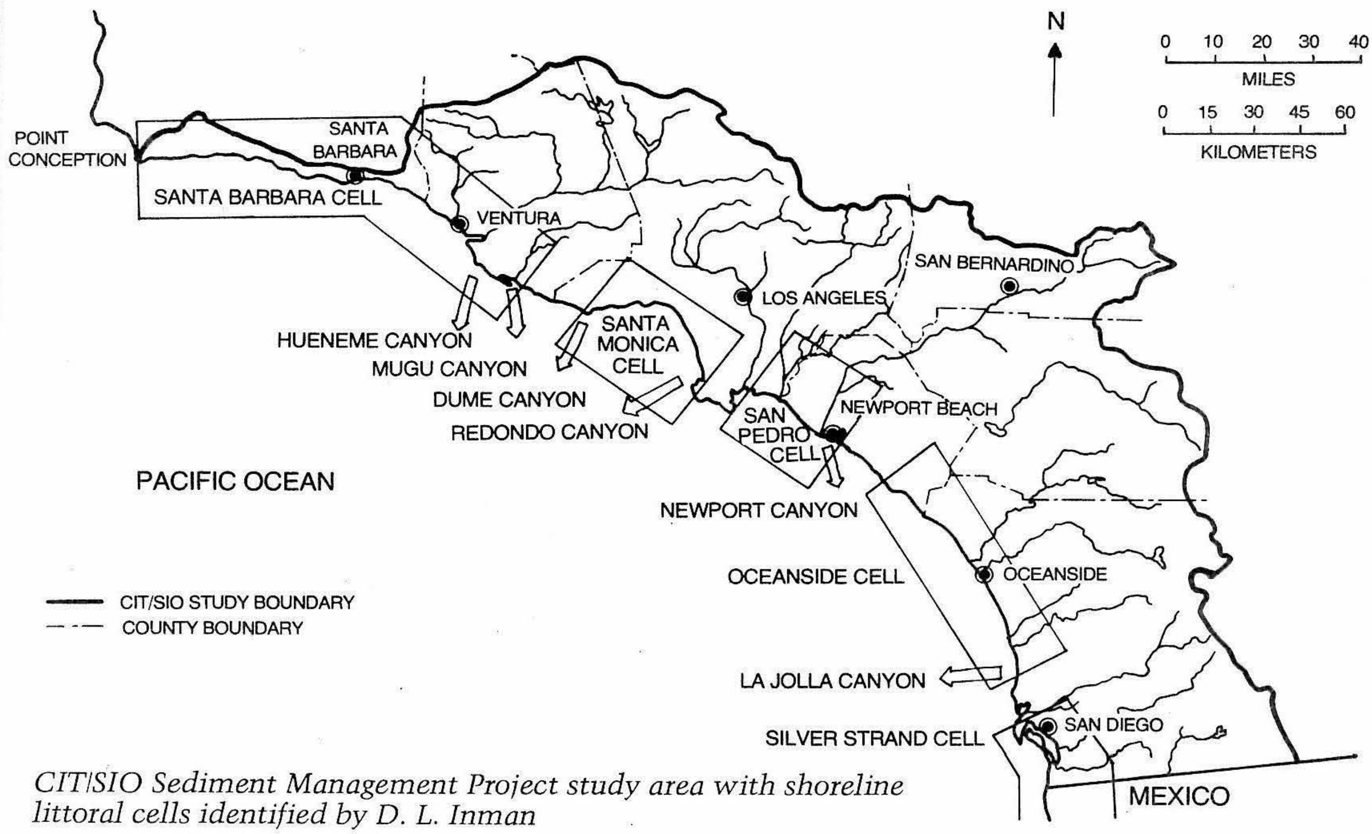
Arthur E. Bruington, chief engineer of the Los Angeles County Flood Control District, discussed the scale of human effects on natural sedimentation in Los Angeles County. He described the complex network of dams and artificial channels that has been superposed on the County's natural drainage system. This control network, and the increasing urbanization that has taken place (with the advent of a large, local population) have altered local sedimentation processes and have brought about significant debris disposal problems, in addition to affecting the natural supply of sediment to the shoreline. However, Bruington noted that no adequate quantitative assessment has yet been made concerning the effect of upstream control structures on the stability of beaches within the respective littoral cells.

In the more than 20 shorter papers presented during the two-day workshop, local sedimentation conditions and problems were discussed for each of the coastal counties in the study area. Although similarities exist in the sedimentation processes and control strategies among the different counties, there are also important differences — for example, in the artificial control imposed on local drainages and in natural sediment factors such as shoreline cliff erosion.

Jeffrey D. Frautschy, member of the California Coastal Commission and Associate Director of the Scripps Institution of Oceanography, presented a review of legislation concerned with coastal development and sediment-management liability, and outlined aspects of forthcoming legislation for the coastal zone of California. Frautschy emphasized that equitable application of certain proposed regulations will require considerable additional knowledge of regional sedimentation processes and of the natural coastal sedimentation balance, particularly as they are affected by human activities.

The workshop concluded with a panel discussion by Joseph M. Caldwell, former Technical Director of the Coastal Engineering Research Center (Corps of Engineers); Henry W. Menard, professor of geology at the Scripps Institution of Oceanography; Ronald S. Shreve, professor of geology at the University

*For a lucid discussion of these processes, see "The Coastal Challenge," by D. L. Inman and B. M. Brush, *Science*, Vol. 181, 1973, pp. 20-34.



CIT/SIO Sediment Management Project study area with shoreline littoral cells identified by D. L. Inman

of California at Los Angeles; and Jeffrey D. Frautschy.

The panelists emphasized the generous natural endowment of recreational beaches in Southern California, and pointed out that despite heavy usage and extensive coastal and inland developments, wholesale damage to these beaches has generally been averted. However, the panel stressed the importance of obtaining adequate quantitative information to define the natural baseline conditions and of identifying the specific effects of human construction. Dr. Menard recommended that creative, enlightened approaches be taken in correcting existing sediment-balance problems and in planning for future development.

Efforts to control local sedimentation processes throughout the coastal study area have been directed toward specific problems — local flood control, beach stability, and so on. Although these efforts have in large measure satisfied their primary purposes, they have perturbed the larger-scale sediment balance. Disposal of sediment from flood-control works is a universal problem throughout the study area, but severe beach erosion is confined at present to a few specific local sites. Coastal zone excavation (e.g. for power plants and marinas) has been an important source of beach replenishment sand in the last few decades, but probably will not be significant in the future. A detailed definition of the natural regional sediment balance is not available, and thus the quantitative effects of these perturbations are not known. In view of the growing concern for comprehensive environmental management, and of the continuing need to improve our economic efficiency in dealing with sedimentation problems, an integrated approach to sediment-management strategies is essential.

Sponsors of the Caltech/Scripps Sediment Management Project

To date the following organizations have become sponsors of the joint Caltech/Scripps Sediment Management Project:

Ford Foundation (through a discretionary grant to the Environmental Quality Laboratory)
Los Angeles County Flood Control District
U.S. Geological Survey, Department of the Interior

Final negotiations are under way with:

Corps of Engineers, U.S. Army Department of Defense
U.S. Forest Service, Department of Agriculture

Negotiations are also under way with several other agencies, so watch for an updated list in a later issue.

We gratefully acknowledge the support given by these organizations, not only for the CIT/SIO project, but also for the publication of this newsletter.

Current Project Work

Since the workshop in March, technical efforts of the project have concentrated on (1) preparation of definitive maps of regional fire histories by decade from pre-1900 to the present, surface runoff characteristics, and artificial controls on inland drainages; (2) analysis of USGS streamflow and sediment discharge data; (3) analysis of upland debris production data (including the effects of fire); and (4) compilation and preparation of preliminary estimates of the annual sediment deliveries to the shoreline by coastal streams and rivers between Point Conception and the Mexican border.

The scale of the map work will be 1:250,000. This mapping scale is standard (USGS); it provides for a single-map presentation of data for the entire study area and is large enough to permit clear delineation of data. The fire maps will give a chronological history by decade of fire frequency and extent of burn throughout the region for the past 70-plus years. This mapping will permit analyses of the historical changes in the frequency, extent, and regional distribution of fire occurrence, and will constitute a basis for analysis of the relative magnitude of fire effects on local sedimentation and on geomorphic processes. Also, it will furnish a data base to evaluate the effects of fire on specific watersheds.

Inland sediment movement is closely tied to movements of surface water. Consequently, the proposed map of runoff depths and peak discharges will help to define quantitatively regional sediment processes and yields.

A third map, now in preparation, will provide a region-wide identification of the type of artificial control on natural sedimentation processes exerted by man-made structures and operating policies. This map will give a qualitative appraisal of the degree of influence man has been exerting on the natural sedimentation processes, and will supply a working drawing for a more quantitative appraisal to follow.

A tentative outline of short project output during the pl

The initial project phase is being directed primarily toward the identification, compilation, and analysis of relevant existing data. This includes data that may be used to define interregional sediment movements important in the natural regional sediment balance, and data helpful in delineating the effects of man-made structures and operations on inland and coastal sedimentation processes.

According to the work plan currently in progress, the following is a tentative outline of specific output and an approximate timetable for the Planning & Assessment Phase.

Short Term Output (Spring 1977)

Data Compilation

Mapping

- Chronological record of regional fire histories since pre-1900
- Regional surface runoff characteristics
- Inland and coastal control structures, with degree of flood/sedimentation control recorded by watershed

Tabulation

- Streamflow and sediment discharge records including debris production measurements
- Dredging histories for harbors and coastal structures (amounts and material sizes, source and disposal locations and dates)

Analyses

Stream Characteristics

- Preparation of sediment discharge rating curves for gaged streams
- Streamflow characteristics: analyses of natural flows versus controlled flows; natural streamflow simulations

First-order estimates of shoreline sand budget: stream inputs, submarine canyon losses, littoral transport rates

Watershed Studies

- Identification of meteorological and physical watershed variables for sedimentation analyses
- Effects of fire on watershed hydraulics and sedimentation

The analysis of streamflow and sediment-discharge data has involved preparation of sediment-discharge rating curves and time-series analyses of historical streamflow records. These results will provide a basis for reconstructing (simulating) historical sediment deliveries through gaged streams. The analysis will also be helpful in quantifying natural stream similarities and dissimilarities in the study area, and will thereby assist in synthesizing historical streamflow and sediment discharge for ungaged streams and for streams with only short periods of records.

The analysis of upland debris-production data is directed toward identifying the meteorological, hydrological, and physical watershed parameters (including fire) that characterize watershed hydraulics and sedimentation production. This analysis will also furnish a basis for identifying interregional watershed similarities and variations in long-term erosion rates at different locations in the study area.

First-order estimates of supply, losses, and transport rates of sand along the shoreline will serve as a guide in uncovering the specific reaches of shoreline where significant sediment imbalances exist. They will also help to identify the reaches where additional data are needed to define the *shoreline sediment budget* in sufficient detail to permit recognition of possible important changes in shoreline morphology.

rm and long-term CIT/SIO
ing and assessment phase.

Longer-Term Output (Spring 1978)

Data Compilation

Mapping
- Regional storm precipitation characteristics
- Geomorphic land classification — geologic stability, weathering and erosion rates
- Shoreline identification — geomorphic types (long exposed beaches, pocket beaches, natural littoral barriers, artificial beaches, artifically modified shoreline), and sedimentology (type and composition of littoral material)

Tabulation and Inventory
- Selected regional storm precipitation data
- Historical beach-profile data (compiled from all sources) for coastal segment between Point Conception and the Mexican border
- Available wave climate data (compiled from all sources)

Analysis

Stream Characteristics

Appraisal of stream morphologies and sedimentation characteristics for controlled and uncontrolled streams and definition of additional data needs to improve these analyses
- Upland watersheds
- Alluvial fans
- Coastal plains

Second-Order Shoreline Sediment Budget Estimates
- Best possible estimates of wave climates along the shoreline from an analysis of wave data
- Development of wave refraction diagrams and calculation of littoral transport at specific localities
- Preparation of improved estimates, where possible, of factors in shoreline sediment budget

Flood/Debris Production Modelling
- Small and intermediate-sized watersheds
- Based on climatic and watershed parameters

Project Leaders

Norman H. Brooks, James Irvine Professor of Environmental Engineering Science; Director of the Environmental Quality Laboratory; Caltech faculty since 1954; fundamental and applied research in open-channel hydraulics, and sedimentation and hydrology (Ph.D., Caltech, civil engineering).

Douglas L. Inman, Professor of Oceanography; Director of the Shore Processes Laboratory, Scripps Institution of Oceanography; twenty-eight years of experience as researcher, teacher, and consultant in coastal oceanography and shore processes (Ph.D., Scripps, oceanography).

Brent D. Taylor, Project Manager; Senior Research Engineer, Environmental Quality Laboratory; returned to Caltech as CIT/SIO project manager after serving four years in the Civil Engineering Corps, U.S. Navy; alluvial hydraulics (Ph.D., Caltech, civil engineering).

Associated Staff

Caltech

William M. Brown, III, Hydrologist, U.S. Geological Survey, Water Resources Division; recently assigned to Caltech; prior work in geomorphology and river mechanics (M.S., Stanford University, civil engineering).

William R. Brownlie, pre-doctoral; experience in stream and shoreline sedimentation (M.S., State University of New York, Buffalo, civil engineering).

Robert C. Y. Koh, Research Associate in Environmental Engineering Science; returned to Caltech after several years of consulting work; hydraulics, fluid mechanics, data processing and analysis (Ph.D., Caltech, applied mechanics).

E. John List, Associate Professor of Environmental Engineering Science; fluid mechanics, applied mathematics and water resources (Ph.D., Caltech, applied mechanics).

Fredric Raichlen, Professor of Civil Engineering; active researcher in wave dynamics and alluvial processes (Sc.D., MIT, civil engineering).

David J. Sarokin, Technical Assistant (B.S., The State University of New York, Purchase, environmental sciences).

Suzanne Sayer, Research Assistant; joined EQL in the spring of 1976; interested in erosional processes and geomorphology (M.S., MIT, geology and geochemistry).

Robert P. Sharp, Advisor; Professor of Geology; Caltech faculty since 1947; formerly Chairman of the Geology Division; geomorphology and alluvial processes (Ph.D., Harvard, geology).

Vito A. Vanoni, Advisor; Professor of Hydraulics, Emeritus, Caltech; associated with Caltech since 1935; in research writing and consulting on hydraulics and sedimentation; editor of widely used new book *Sedimentation Engineering* (Ph.D., Caltech, civil engineering).

Patricia McCall, Administrative Secretary.

Scripps

Charles E. Nordstrom, Associate Specialist in Marine Geology; joined staff of the Shore Processes Laboratory in 1960; research and consulting work in coastal geology and shore processes (M.S., Scripps, geology).

Kim Kastens, pre-doctoral student; experience in coastal processes and geomorphology (B.S., Yale, geology).

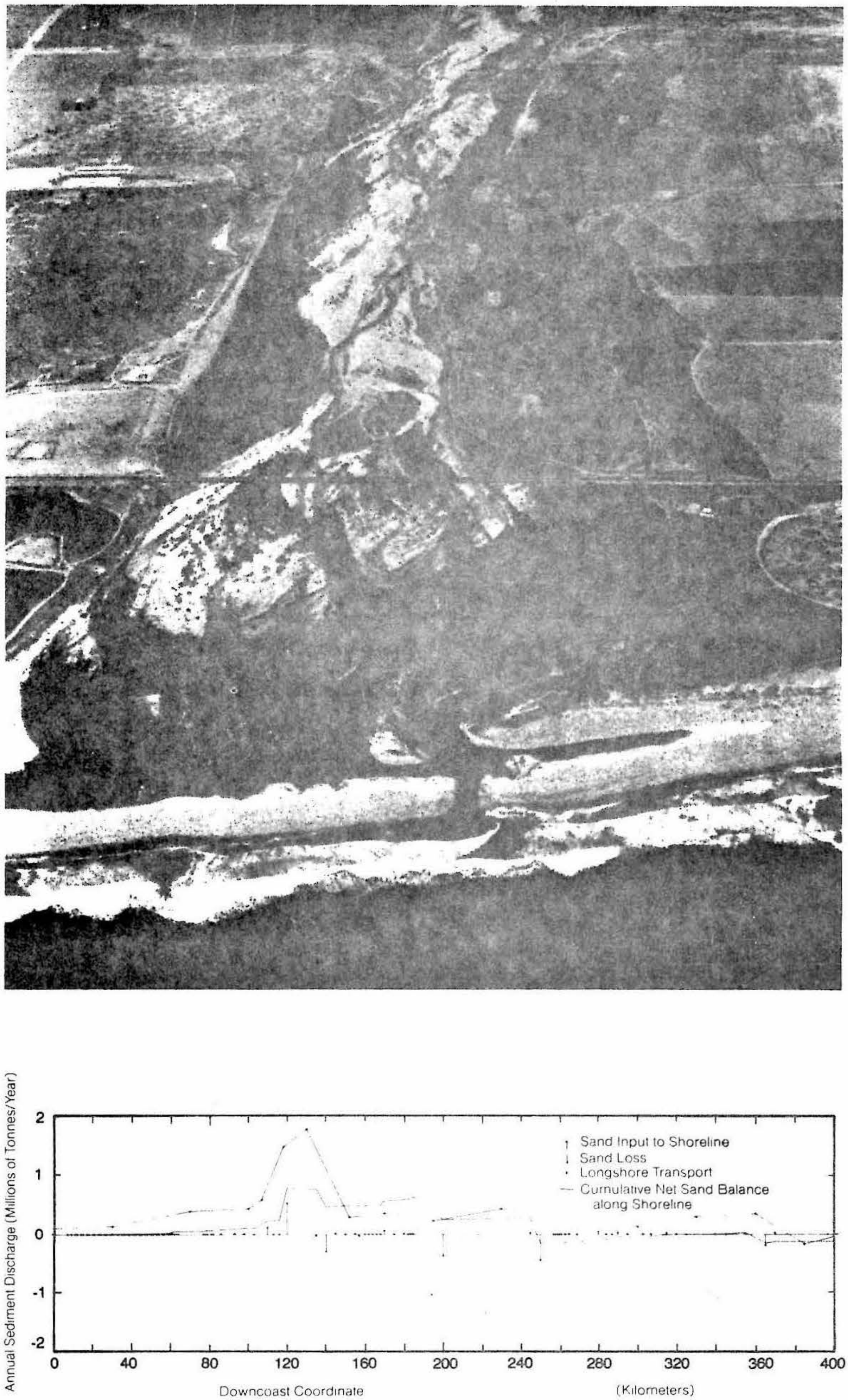
Jean Keefner, Administrative Secretary.

Summary of Available Data at EQL

Technical efforts on the assessment phase of the CIT/SIO project have resulted in the location, collection, and analysis of a wealth of pertinent data. These data presently are being culled, collated, and entered into appropriate bibliographic, map, and computer files at Caltech. The data comprise:

1. **Streamflow data:** specifically, daily mean and annual peak flows for several hundred large and small streams throughout the study area. A master list of all available streamflow records has been obtained from the California Department of Water Resources and has been entered onto magnetic tape for ready computer access. The list encompasses 852 stations in the study area at which streamflow data have been collected. Some 450 of these stations have been operated by the U.S. Geological Survey, and the master computer files of the USGS have been accessed to transfer useful data to the Caltech files.

2. **Sediment-transport data:** specifically, daily mean discharges and individual sample data for both suspended-sediment and bedload transport. These USGS data are derived from 32 stations in the study area, of which
(a) 20 stations have from 1 to 9 years of records;
(b) 10 stations, primarily on upland drainages in the Santa Clara River basin, have records;
(c) 2 stations (the Los Angeles and San Gabriel Rivers near their mouths) were established in late 1975 specifically for the project;
(d) 10 stations have 1 to 2 years of bedload data;
(e) 11 of the 20 stations are on the main stems of rivers near their points of discharge to the ocean.
Some 110 station-years of daily suspended-sediment discharge data are available from the USGS. These data have been obtained in punched-card format and have been entered onto magnetic tape and disk. Data on the particle-size distribution of suspended sediment and bedload are being entered onto computer cards for immediate analysis and subsequent entry onto tape or disk.



Aerial photograph of the Santa Clara River near its mouth with a graphical presentation of shoreline sediment budget for a hypothetical coastal reach superposed. (Photo by Lynda Chivers)

3. **Geologic data:** specifically, color and black-and-white vertical aerial photographs and color infrared vertical aerial imagery. An inventory of existing imagery shows that more than 100,000 images are available for the study area from the USGS, National Aeronautics and Space Administration, National Oceanographic and Atmospheric Administration, U.S. Forest Service, and other public and private sources. EQL is currently selecting from this vast store of images a reasonable, useful amount of coverage on which we can build as the project progresses. A compilation of flight lines, image centers, and image scales for USGS, NASA, NOAA, and USFS data is now on file at Caltech. Additional aerial photography is available at Scripps. A precision scanning stereoscope has been loaned to the project by the USGS for inspection and analysis of stereoimagery.

5. **Beach and offshore sediment-size data:** specifically, size-distribution data for 95 samples in Ventura, Los Angeles, Orange, Santa Barbara, and San Diego Counties by the Los Angeles District, Corps of Engineers, for the period 1967-69. More than 350 additional sand samples at various locations along the coast of the study area were obtained and analyzed by the Corps from 1963 to 1966. These data initially will be used (a) to determine the spatial and temporal variations in the sizes of materials that make up the beach, (b) to relate these variations to the regimen of sand discharge by streams, and (c) to locate areas that lack a suitable data base so that an appropriate sampling program may be instituted.

6. **Fire history data:** specifically, maps of the extent and dates of forest and brush fires that have occurred in the study area during the past 75 years. These data have been collected from county agencies and the U.S. Forest Service, and have been compiled on a single 1:250,000 base map. Fire histories for each decade will be extracted for compilation on map overlays that will be used to point up relationships to hydrologic events that occurred during each period.

7. **Sand and gravel mining data:** specifically, location, quantity, and size distribution of sand and gravel mined in the study area. These data will be compiled primarily from reports by the California Division of Mines and Geology, and will be used to help assess the magnitude of distribution of sediment by human activity. A knowledge of the demand for sand and gravel will aid in weighing alternatives for disposal of material that must be excavated from flood-control and debris basins.

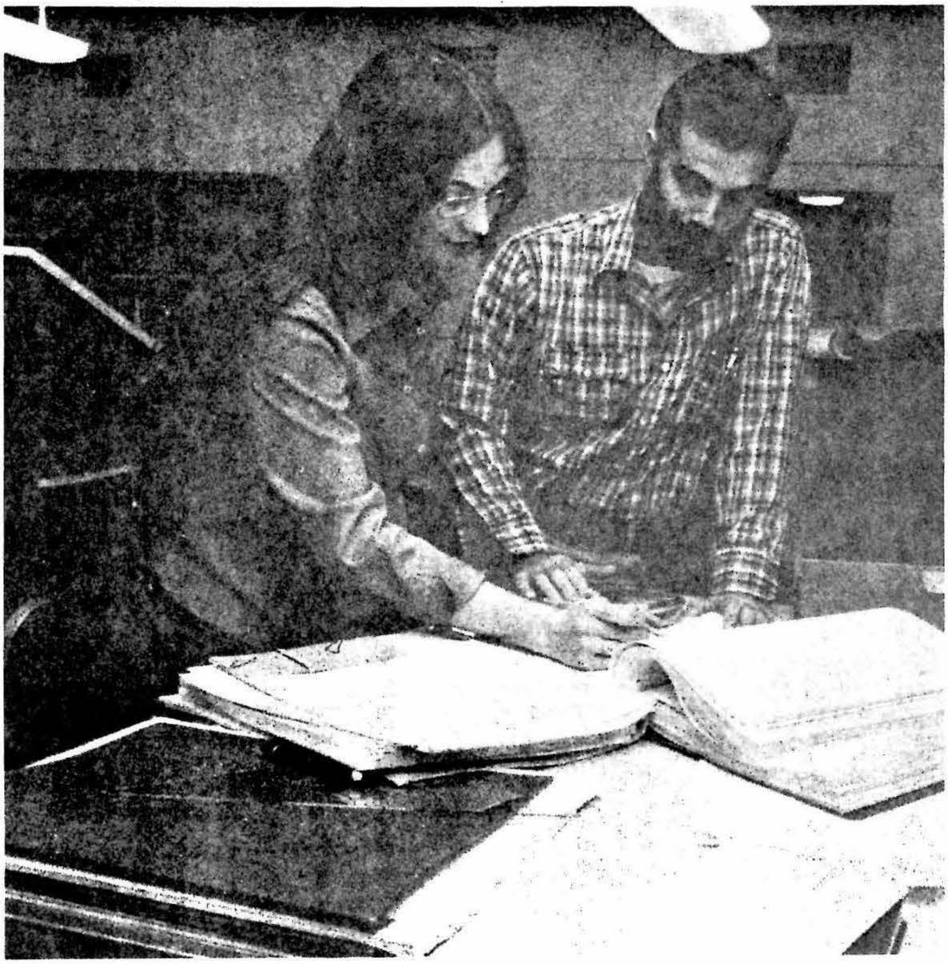
This growing data base will have the singular advantage of putting into usable and accessible form a large body of sedimentation data that have been heretofore dispersed and sometimes difficult to identify and obtain. Anyone wishing information concerning data access, or procedures for obtaining duplicate data tapes, is encouraged to get in touch with Brent Taylor at EQL (213-795-6811, ext. 2658).

Coastal Legislation Implies Need for Increased Knowledge of Coastal Processes

State legislation (Senate Bill No. 1277) to impose permanent controls on the development of California's 1725-kilometer coastline was approved by the California Legislature in August 1976. The new law demands preservation of certain aspects of the coastal environment, expanded public access to the coast, and comprehensive planning by local governments for future building. These requirements point up the need for wide-ranging scientific studies of the coastal zone. A better understanding of the physical aspects of coastal streams and beaches — flooding, erosion, response to channelization, and the like — will help to provide a rational basis for intelligent planning.

The legislation specifically treats

(continued on page 8)



Suzanne Sayer and David Sarokin, new Research Assistants at EQL.

Southern California Sediment Management Newsletter
California Institute of Technology
Environmental Quality Laboratory, 314-40
Pasadena, California 91125

Non-Profit Org.
U.S. Postage
PAID
Pasadena, Calif.
Permit No. 583

(continued from page 7)

sediment management issues. For example, Chapter 3, Article 4, of the Act relates to the alteration of natural streams, filling and dredging, and shoreline structures. Chapter 8 is devoted entirely to findings and policies concerning port facilities at Port Hueneme, Long Beach, Los Angeles, and San Diego. This chapter encourages expansion of the ports within their present boundaries "in order to minimize or eliminate the necessity for future dredging and filling to create new ports in new areas of the state." Restrictions on diking, filling, or dredging within the ports are also specified. Other policies in the Act treating sediment management in the coastal zone suggest that there is much work to be done in sediment data collection, analysis, and interpretation.

The California Coastal Act of 1976 (Senate Bill No. 1277) and its companion amending bill (Assembly Bill No. 2948) may be obtained from the California Legislature, Senate Committee on Natural Resources and Wildlife, Sacramento, California, 95814; telephone 916-445-6091.

'We interrupt the sound of the sea to bring you this important message: Save the coastline!'

Dennis Renault — Sacramento Bee

Editor's Note

Southern California
SEDIMENT MANAGEMENT
NEWSLETTER

Editor: Suzanne Sayer
Graphics: Margi Schulz Design

The Southern California Sediment Management Newsletter is published periodically by the Environmental Quality Laboratory to report on the CIT/SIO Sediment Management Project and other developments in regional sediment management.

Printed on 100% recycled paper.

Number 2
Summer 1977

Southern California Sediment Management Newsletter

Environmental Quality Laboratory, California Institute of Technology, Pasadena, California
Shore Processes Laboratory, Scripps Institution of Oceanography, La Jolla, California

U.S. Forest Service Studying Watershed Vegetation

Wade Wells

Chaparral is a vegetation type that dominates the upland watersheds of the Southern California coastal zone. Unlike most other vegetation types, it is characterized not so much by a dominant species composition as by its typical growth form of stout, dense, densely rooted shrubs which tend to form nearly impenetrable thickets. Chaparral, despite its lack of commercial value, is of special interest to the U.S. Forest Service because it protects the watersheds and upland basins which drain to the heavily populated coastal area, and because of the potential dangers of fires and floods in the chaparral zone.

Over 80% of the National Forest lands in Southern California are covered with chaparral, and their proper management is a matter of daily concern to land managers both in and outside the Forest Service. Unlike vegetation types which have high commercial value, chaparral and its related ecosystem have not received much attention from research workers, and consequently there is a decided lack of knowledge

(continued on page 2)

Sediment Management Project Update

During the six intervening months since the publication of our first newsletter there has been notable progress in our technical studies. Two agencies, Orange County Environmental Management Agency and the Corps of Engineers have made significant financial commitments for project support, a letter of agreement for ongoing cooperative technical support has been signed with the U.S. Forest Service, and we have made some additions to our project research groups at Caltech and Scripps (see article on page 11).

Looking back over the past year and a half since the beginning of the project, the number of supporting agencies as well as the overall level of commitment has continually grown.

A vital part of our study continues to be the establishment of an integral working relationship with all of the federal, state, and local agencies that have primary responsibility for sediment management in Southern California. In this area there has also been sustained progress. With the advent of the project in September 1975, Dan Davis, head of the Watershed Erosion Control Section at the Los Angeles County Flood Control District, began to work closely with Caltech on technical subtasks especially pertaining to District activities. A few months later the Geological Survey assigned Bill Brown, an engineering hydrologist, to work full time at the Environmental Quality Laboratory on inland sedimentation processes. Then Orange, San Diego, and Ventura counties each designated a staff member to assist with data compilation and analysis: Herb Nakasone, Orange County Environmental Management Agency; Joe Hill, San Diego Department of Sanitation and Flood Control; and Gerry Bickel, Ventura County Department of Public Works.

Earlier this spring the U.S. Forest Service initiated a letter of agreement with Caltech which would provide for a research hydrologist, Wade Wells, from the Pacific Southwest Forest and Range Experiment Station to work two days per week at the Environmental Quality Laboratory on special upland erosion studies. The Los Angeles District Office of the Corps of Engineers is also in the process of arranging for the part-time assignment of a staff hydraulic engineer to the Sediment Management Project.

(continued on page 4)

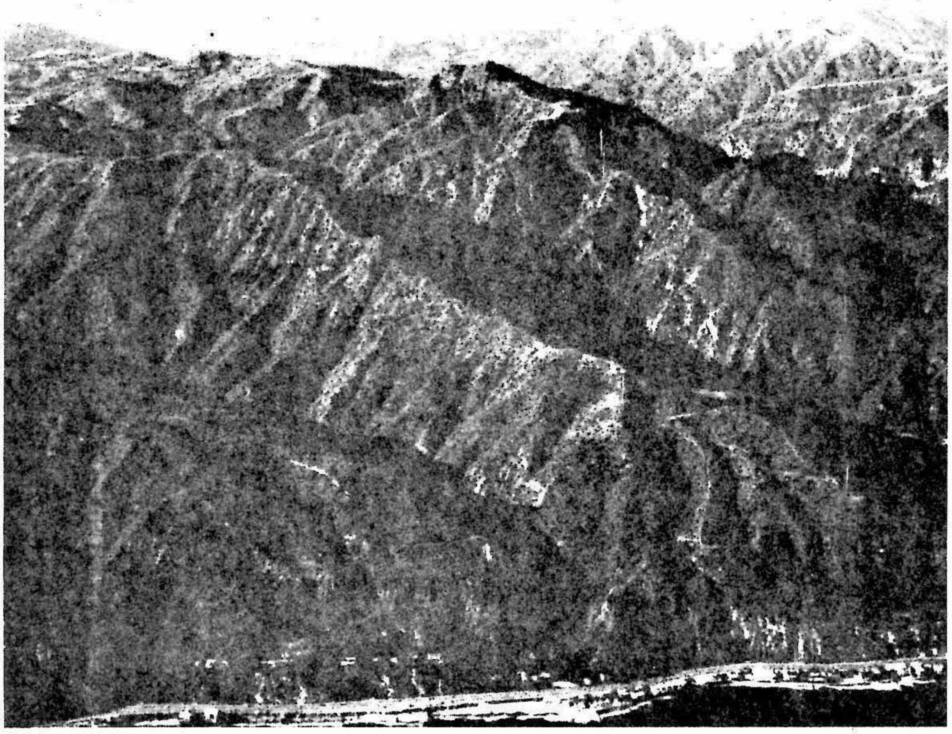
(continued from page 1)
about what takes place in the chaparral environment. Because of this, the Forest Service has recently launched an applied research and development program aimed at increasing the general knowledge about the chaparral zone in order to develop guidelines for its more effective management.

This R&D program is designed to address all aspects of the chaparral related ecosystem and to emphasize research with immediate practical application. The two great dangers in the chaparral zone are wildfires and floods, both of which have a major effect on erosion and inland sedimentation problems in Southern California. Much of the research effort will be directed specifically at these two problems. In addition, work will be done in the fields of nutrient cycling, wildlife biology, plant physiology (including the effects of smog), fire management, and vegetation manipulation. Although basic research is not a major objective of this program, some basic research is anticipated to support the program's applied research objectives.

The program headquarters is located at the USFS Forest Fire Laboratory in Riverside. However, the bulk of the research will be handled by the Forest Service Research Work Unit located at Glendora, near the San Dimas Experimental Forest, and at the Fire Lab in Riverside. Several universities throughout California are cooperating with the Forest Service by providing input to the program and by integrating some of their research activities with those of the chaparral program. A recent workshop on program objectives was attended by scientists and engineers from the University of California (Berkeley, Davis and Riverside campuses), California State University (San Diego and Fullerton campuses), California Polytechnic Institute (Pomona), and Caltech.

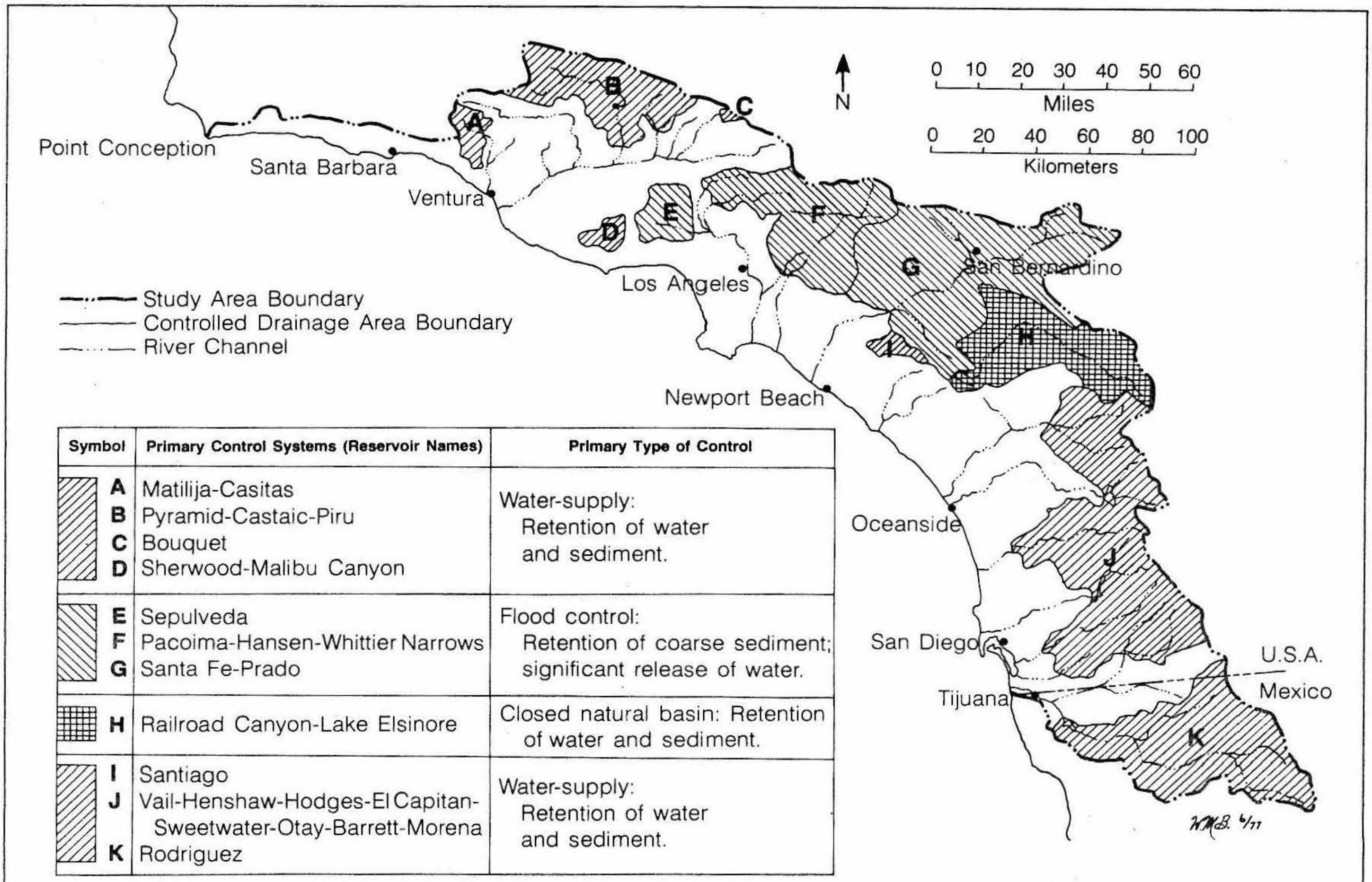
The program is also receiving support from various land management agencies and citizens groups in Southern California. In addition to the five National Forests of Southern California (Cleveland, San Bernardino, Angeles, Los Padres, and Sequoia) cooperative assistance is being received from the Los Angeles County Flood Control District, the San Diego County Department of Sanitation and Flood Control, the Los Angeles County Fire Department, the National Park Service, Bureau of Land Management, Bureau of Indian Affairs, California Department of Forestry, and the Southern California Watershed Fire Council.

The program is designed to run for five years and has several specific objectives which include development of a resource inventory and classification system, a set of prescribed burning guidelines for management by controlled fire, and a basic understanding of the physical and biological processes occurring in the chaparral ecosystem. Its ultimate goal is to make as large a contribution to "state of the art" knowledge as possible and to provide a better basis for managing this important ecological zone.



The Santa Monica Mountains above Malibu are a good example of mountain watersheds draining directly to the coast.

Wade Wells is a hydrologist with the U.S. Forest Service Research Work Unit in Glendora.



Symbol	Primary Control Systems (Reservoir Names)	Primary Type of Control
A B C D	Matilija-Casitas Pyramid-Castaic-Piru Bouquet Sherwood-Malibu Canyon	Water-supply: Retention of water and sediment.
E F G	Sepulveda Pacoima-Hansen-Whittier Narrows Santa Fe-Prado	Flood control: Retention of coarse sediment; significant release of water.
H	Railroad Canyon-Lake Elsinore	Closed natural basin: Retention of water and sediment.
I J K	Santiago Vail-Henshaw-Hodges-El Capitan-Sweetwater-Otay-Barrett-Morena Rodriguez	Water-supply: Retention of water and sediment.

Sediment Management Project Study Area Showing Major Drainage Basins Controlled by Dams

Fire Frequency Study Nears Completion

William M. Brown III

Nearly all upland regions in the study area have burned at least once and some areas have burned as many as five times since the turn of the century, according to data compiled for the regional fire history segment of the project. These results coupled with the extreme effect watershed burning has on surface erosion indicate that fires in Southern California are a significant geomorphic force in shaping upland terrain and accelerating the delivery of sediment to alluvial fans, coastal plains and the shoreline.

In order to examine the regional fire history, a series of seven "decade" maps has been compiled. Each map identifies the location and areal extent of the forest, brush, and grass fires 40 square hectometers (100 acres) or larger that have occurred in upland areas. Six of the maps depict burns during 10-year intervals from 1910 through 1969, and the seventh covers the 6-year interval 1970–75.

Basic data for these maps were collected from a variety of sources including the U.S. Forest Service, Flood Control Districts in seven counties, and other regional and local agencies and individuals.

Each of the seven maps was drawn on transparent film registered to a scale-stable topographic base map produced expressly for the study by the U.S. Geological Survey. The map scale is 1:250,000 and therefore, to accommodate the crescent-shaped study area, the maps measure approximately one meter wide and two meters long.

These maps will be published by the U.S. Geological Survey as part of a Hydrologic Atlas series. Included with these maps will be a quantitative summary of the regional fire history which will detail total area burned each decade by physiographic unit and drainage basin, and a composite map to show burn frequency since 1910.

In addition to the USGS publication of these maps, the seven individual "decade" maps will be made available to cooperating agencies on an *open-file basis* beginning in July.

Bill Brown is a hydrologist with the U.S. Geological Survey, currently assigned to the Sediment Management Project.

(continued from page 1)

The level of outside interest in the project has grown steadily since its inception. Inquiries and conversations with a variety of local, national and international agencies and individuals suggest that through the two-day workshop held a year ago, the first issue of our newsletter, special presentations, and other contacts, a wide interest and expectation has been focused on the Sediment Management Project. This interest and intangible support is helpful and appreciated.

By the conclusion of the coming year (July 1977–June 1978) we hope to complete the primary work elements in the Planning and Assessment Phase that were outlined in the first newsletter. Perhaps the most important of these elements will be the detailed quantitative description of natural regional (inland and coastal) sediment movements afforded by data currently available.

Again we would like to encourage our readers to submit short articles, letters to the editor, notices of upcoming events, etc., for publication in the newsletters. We want to make this publication a lively and open forum for technical and non-technical sediment management issues in our area.

Beach Profile Analysis Underway at Scripps

Douglas L. Inman, Charles E. Nordstrom, and David G. Aubrey

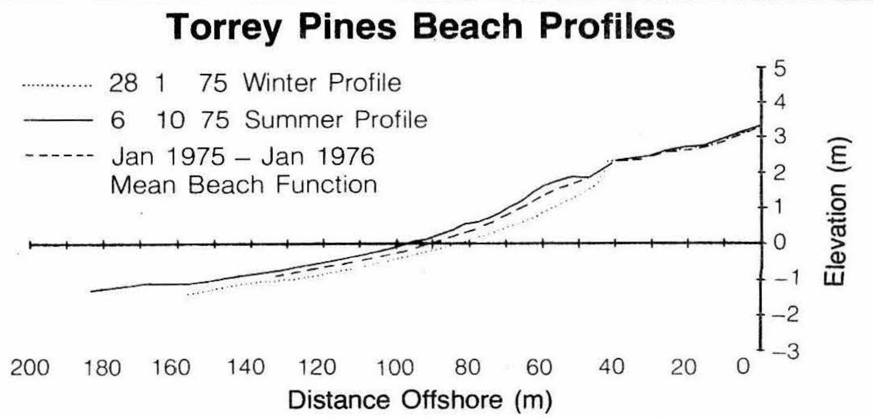
Beaches are dynamic physical features which undergo abrupt changes under storm waves as well as longer term changes resulting from seasonal variations in wave climate or disruptions in sediment sources. Beach profiles measured periodically at the same site are useful in documenting these changes in configuration and provide a time history of coastal sedimentation. Thus, beach profile data from the Sediment Management Project study area are essential to understanding regional sedimentation processes.

Beach profiles have been measured at numerous places in the study area for varying lengths of time by several agencies; however, most of these data sets vary in accuracy, scale and vertical exaggeration and must be standardized for direct comparison. The initial step in the study of beach profile data will be a comparison and analysis of all existing data in order to ascertain data gaps and determine if obvious trends are present in the available information.

Compilation of sets of beach profile data involves collecting the information from the various sources and transferring it into a standardized digital format. Most beach profile data is in the form of graphic plots that lack the original numerical data and must be digitized into distance-elevation pairs for each data point on the profile. Standardization of the data with respect to units of measurement (such as feet to meters) and standard reference elevations is also done as part of the processing scheme. All elevations are referenced to mean sea level and distances to an established benchmark so that all profiles can be accurately located. The final product of this data processing is a description of each profile reduced to a set of distance-elevation pairs that are stored either on IBM punch cards or on magnetic tape for future reference. The digitized data are entered into the computer and stored on magnetic tape with rangeline and data identifiers.

Several computer programs are available to process the beach profile data as indicated in the accompanying flow diagram. Plotting routines are available to plot any one profile with up to four other profiles for a direct comparison as a single illustration. The output of the printer-plotter is camera ready for publication which simplifies the graphic preparation of data. A series of computer routines is available for comparing series of profiles and calculating the volume changes in sand level on the beach. These changes can be plotted on the printer-plotter to graphically illustrate the erosion and accretion areas on the beach.

A third series of computer routines is available to make statistical comparisons of sequences



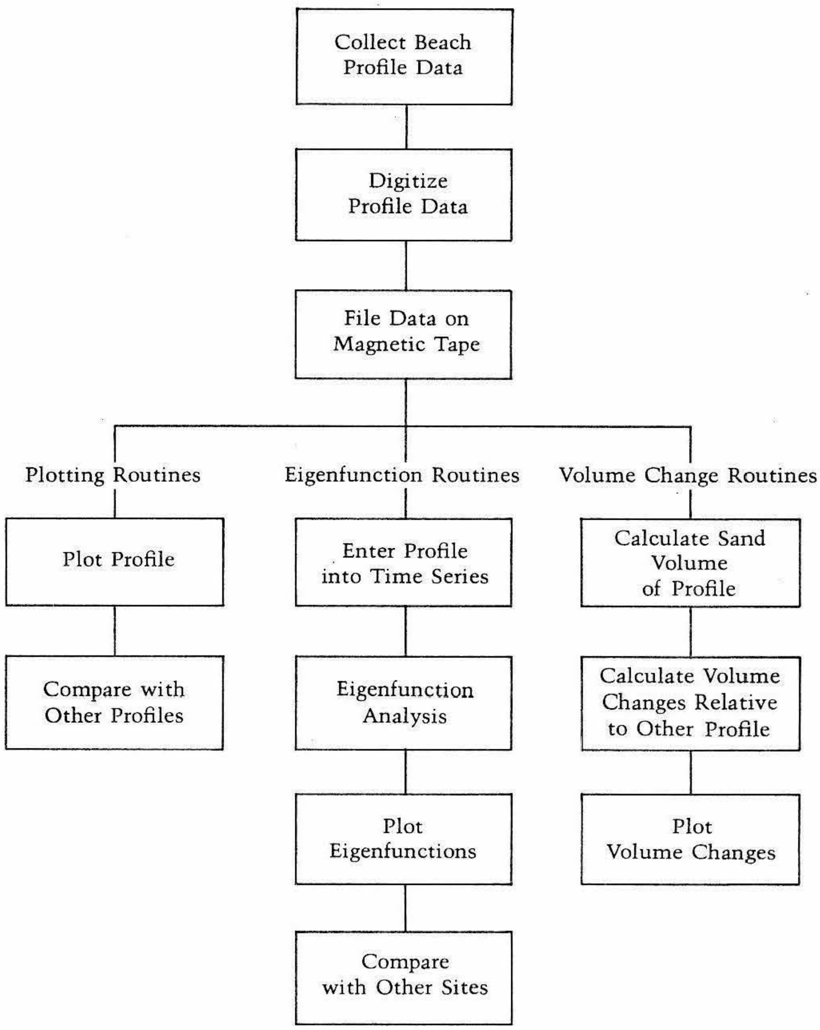
Computer plot of mean beach eigenfunction and maximum accretionary profile and maximum erosional profile at North Range, Torrey Pines Beach, California for 1975–76.

of beach profile data that are longer than a year and have sample intervals of one month or less. These routines are designed to analyze beach profile data using empirical eigenfunctions* to characterize the primary modes of profile variability. Eigenfunction analysis is useful for comparing extended time series data sets from different sites in terms of both seasonal and short term changes. The beach profile graph shows a comparison of the first eigenfunction, the mean beach function, with the maximum accretion and erosion profiles at Torrey Pines Beach, California. Other eigenfunctions defined by this analysis describe the variation of the profile data from the mean beach function for all data points on the profiles and for every profile measured at a site.

The data processing scheme outlined above has been developed specifically for the efficient handling of beach profile data with an Interdata Model 70 mini-computer system. Since it has been in use, a sizable library of beach profile data has been compiled from around the world for general reference. However, the Sediment Management Project will focus data processing efforts on beach profiles from the study area in order to further research on this aspect of the project.

Douglas Inman is a Professor of Oceanography and Director of the Shore Processes Laboratory at Scripps. Charles Nordstrom is an Associate Specialist in Marine Geology and has been with the Shore Processes Laboratory since 1960. David Aubrey is a doctoral student in physical oceanography.

Beach profile data processing scheme.



---

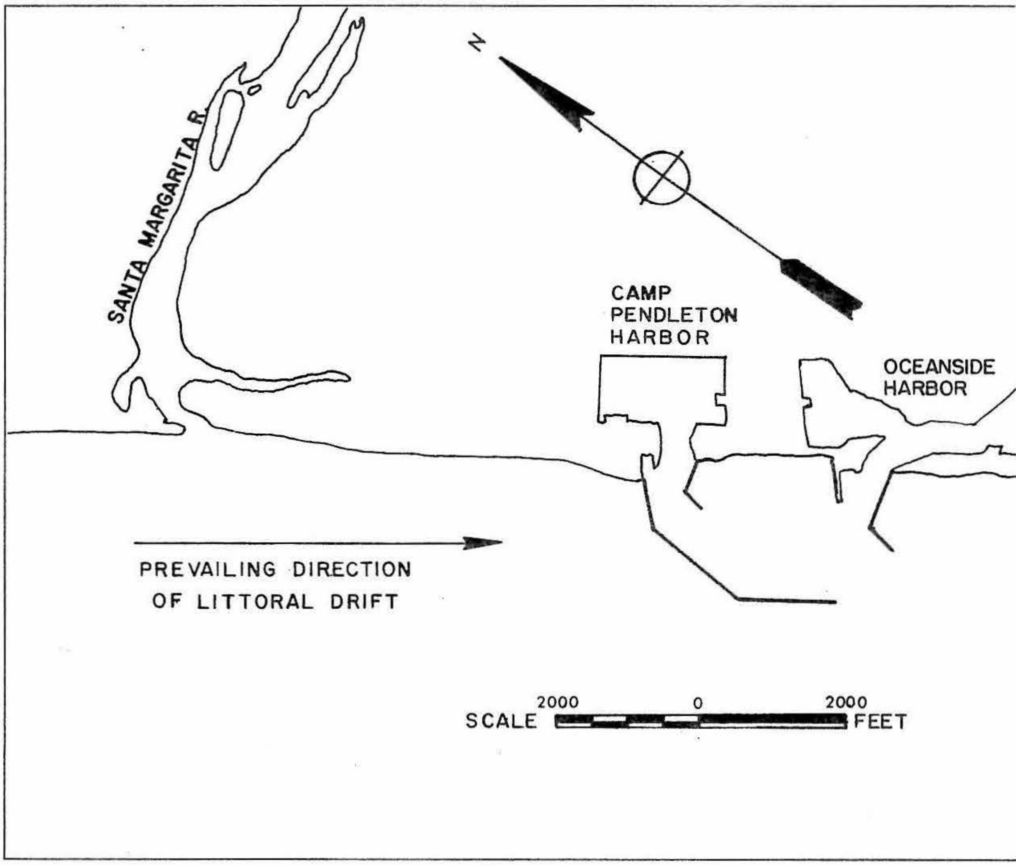
*For a discussion of empirical eigenfunctions and beach profile analysis, see:

Winant, C.D., D.L. Inman, and C.E. Nordstrom, 1975, "Description of seasonal beach changes using empirical eigenfunctions," *J. Geophys. Res.*, Vol. 80, No. 15, pp. 1979–1986.

Winant, C.D., D.G., Aubrey, in press, "Stability and impulse response of empirical eigenfunctions."

Beach Erosion at Oceanside: A Case Study

Brent D. Taylor



One of the reaches along the Southern California coast that has suffered severe shoreline erosion in recent years is near Oceanside. The beach downcoast of Oceanside pier has periodically been eroded down to bare cobbles. Almost $7 million has been spent in an attempt to stabilize this beach area.

At Oceanside, as is true all along the coast even under pristine conditions, the local sediment budget is rarely, if ever, balanced in terms of input equalling local output on an annual or longer-term basis. Littoral transport is an unsteady process over all important time scales and sediment delivery to the shoreline by coastal streams and rivers can vary several orders of magnitude during a given year and from one year to the next. We do not yet know enough quantitatively about these natural fluctuations to assign specific effects to specific causes and thereby create a detailed quantitative model of coastal alluvial morphology. Also, the available historical data is inadequate to permit operation of such a detailed model over a long enough time scale to identify the range of natural variations in shoreline and beach configuration. Therefore, it is not easy to assess the current erosion problem at Oceanside completely and separate the effects of man-made perturbations from those of nature.

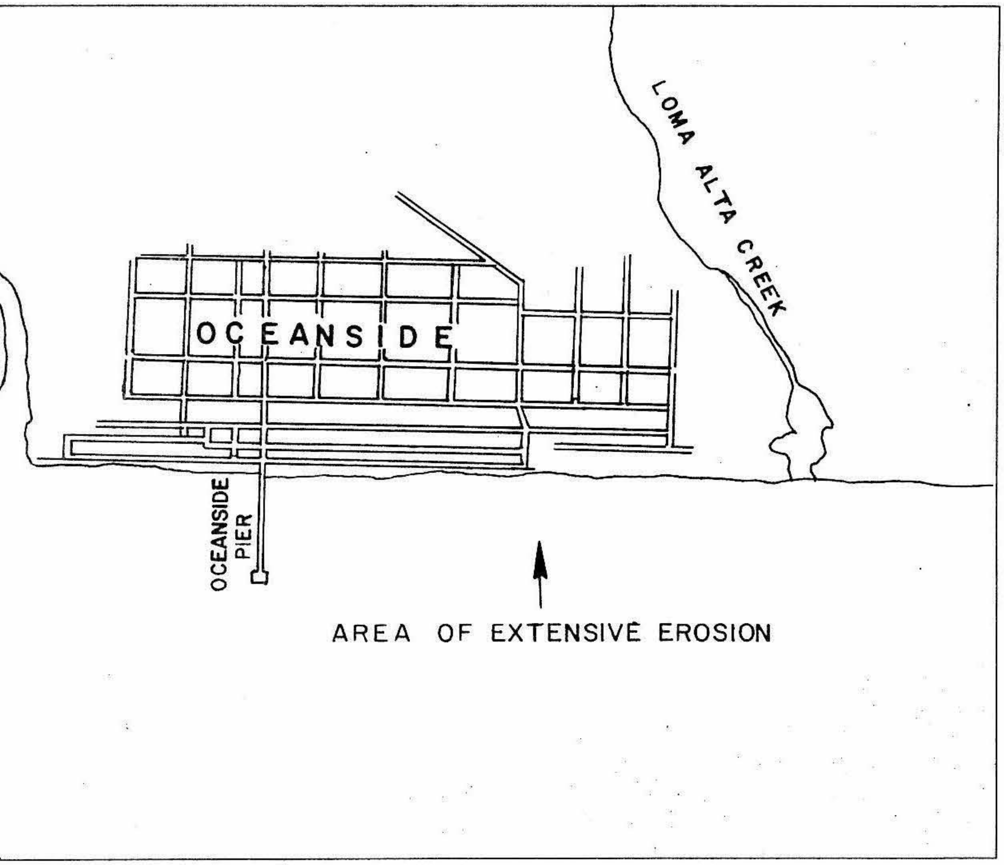
However, it is possible to identify in a general sense probable quantitative effects of significant man-induced perturbations that affect sediment movement in a local area.

In the vicinity of Oceanside, prior to 1922, there was little human development and virtually no artificial controls on the natural sediment system. In 1922, the dam creating Lake Henshaw was completed on the upper drainage of the San Luis Rey River, reducing the uncontrolled drainage area of the river basin from 1445 km² to 911 km², or 37%. This reservoir serves primarily as a water conservation facility and has caused a significant reduction in the volume of water flowing to the ocean.

In 1943, the Department of Defense constructed the Del Mar Boat Basin to augment wartime military activities at nearby Camp Pendleton. Since its construction this coastal structure, with later modifications, has served to effectively interrupt the natural movement of beach-sized sediment along the coast at Oceanside. This interruption has been partially alleviated by periodic bypass-dredging operations by the Navy and Army Corps of Engineers.

In 1949, Vail Lake, a major water conservation reservoir, was completed on the Santa Margarita River. This reservoir controls 829 km² of the 1917 km² Santa Margarita drainage (43%). Both Vail Lake and Lake Henshaw have trapped the natural sediments eroded from the landforms above the dams, reduced total runoff of the two rivers, and reduced peak storm discharges in the lower reaches of the rivers. Each of these separate effects reduces the amount of sediment delivered to the coastal zone.

Study efforts on other watersheds give us an indication of the effects of controls on sediment delivery to the beaches. On the Ventura River, for instance, 230 km upcoast from Oceanside, the total reduction in sediment delivery is approximately the same as the reduction in uncontrolled drainage area on the



A once sandy beach near Oceanside has been reduced to cobbles by the effects of erosion.

inland watershed (see Ventura River article, page 8). This would suggest that Lake Henshaw and Vail Lake have effected reductions on the order of 40% in coastal sediment delivery by the San Luis Rey and Santa Margarita Rivers.

The combined drainage areas of the San Luis Rey and Santa Margarita Rivers account for a large fraction of the total coastal drainage that delivers sediment to the shoreline at, and upcoast from, Oceanside in the littoral cell associated with the area [see map in Newsletter #1]. Therefore, a 40% reduction in the shoreline sediment delivery by these two rivers could cause a considerable reduction in the amount of sand available to replenish the Oceanside beaches. If this is true, a solution to the human perturbation on the dynamic natural sediment budget system in the vicinity of Oceanside will require an ongoing artificial subsidy of beach-sized sand near the mouths of the San Luis Rey and Santa Margarita Rivers to supplement reduced natural deliveries as well as to provide for a more natural (continuous) sand bypassing operation around the Del Mar Boat Basin.

On April 17, the Los Angeles District of the Corps of Engineers held a public meeting at Oceanside to discuss different possible technical solutions being considered. After more detailed studies, one of these alternatives will be implemented by the Corps, which has been given the responsibility by Congress to implement a permanent solution to the man-induced shoreline instability problem at Oceanside.

Brent Taylor is the Project Manager of the Sediment Management Project at EQL.

Sediment Discharge on the Ventura River

William Brownlie and David Sarokin

Analysis of data from the Ventura River watershed has resulted in preliminary estimates of the effects of upstream controls on delivery of sediment to the shoreline. Results indicate that the completion of Matilija Dam in 1949 and Casitas Reservoir in 1959 has significantly reduced the total volume of streamflow to the Pacific Ocean, with a consequent decrease in sediment transport.

The Ventura River drains 585 km^2 of inland drainage. Annual precipitation on this watershed ranges from 40 cm in the lower areas near sea level to more than 80 cm in the mountain areas above 1500 meters. The surface geology is principally comprised of colluvial and landslide deposits developed on the sedimentary bedrock. Vegetation is fairly uniform and consists primarily of chaparral except in the highest parts of the watershed where there are extensive rock outcroppings.

The Ventura River drainage basin, northernmost of the nine major rivers in our study area, was selected as our first attempt at sediment yield modeling. Its small size, good data base and the clarity of its control history provide the basis for a relatively straightforward statistical model of the effect of control structures on sediment delivery to the ocean.

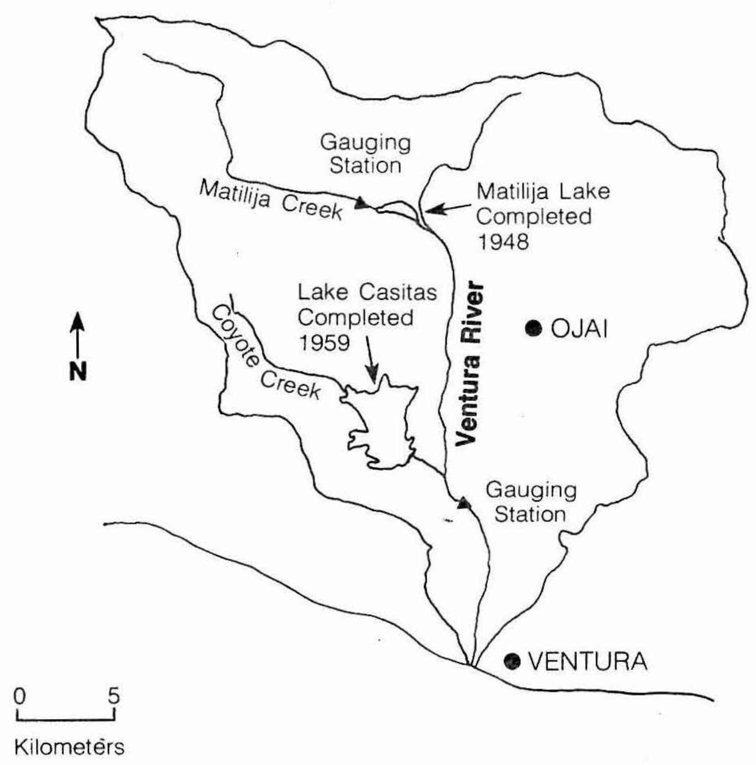
Control structures can influence sediment delivery in several ways. Flood control projects attenuate peak storm flows, but may not necessarily alter the total annual water discharge of a river. Water supply reservoirs, like those on the Ventura River, store the inflow of water, effectively reducing the drainage area of the watershed with a consequent reduction of the annual discharge. Both types of reservoirs trap sediment which would have been delivered to the lower reach of the river.

Our strategy of sediment delivery modeling on the Ventura River has three steps. (1) The first step is the determination of the effect of control structures on the volume of streamflow which is discharged to the ocean. (2) The second step is the establishment of a relationship between streamflow and sediment discharge. (3) Finally, the results from steps (1) and (2) are combined to produce estimates of actual sediment delivery, and sediment delivery as it would have occurred if the control works had not been built. With this general procedure and available data, we were able to obtain quantitative estimates of man's influence on the sediment delivery to the ocean.

The basic technique for step 1 of the modeling is the *Double Mass Analysis*. This technique, as it applies to the Ventura River, is illustrated in the figure on page 10. Here, the cumulative annual discharges for two stream gauging stations have been plotted; thus the term "double mass." Matilija Creek is a small uncontrolled stream, while the Ventura River station is downstream of the two major control structures. The initial section of the curve represents the period 1934 to 1948. During this period human influence on runoff was small. The correlation between the cumulative discharges of the two stations is quite high for this portion of the curve, which is represented as a straight line. The dotted extension of this line provides an estimate of expected cumulative annual discharges from the Ventura River without the influence of the control structures. The effect of the structures, Matilija Dam (1948) and Casitas Dam (1959), is shown to have considerably reduced the discharge from the Ventura River.

Unlike streamflow data, sediment discharge data is relatively scarce for most streams in our study area, and the Ventura River is no

(continued on page 10)



Map File Expands

Our map file is growing rapidly as we continue to compile an extensive set of maps pertaining to the study area. We have 1:250,000 scale geologic maps of the entire study area (including northern Baja California), and some 50 recently published maps depicting surficial and bedrock geology at a scale of 1:24,000. Many of these maps were produced in conjunction with formal reports of the U.S. Geological Survey and the California Division of Mines and Geology. However, we have also been fortunate in obtaining unpublished maps from a variety of sources. The maps are being used primarily to categorize the erosion potential of upland watersheds. Some of these maps are also available for inspection and reproduction by cooperating agencies.

Our topographic and bathymetric map file includes some 300 topographic maps of 1:24,000 scale, and many other smaller scale maps. These maps include, among other things, definitions of the many submarine canyons off the coast in Southern California, general classifications of land use and land cover, and resolution of the topography of the Tijuana River Basin lying in Mexico — a wealth of information readily available for project use.

New Theory Proposed

Project Director Norman H. Brooks recently commented that if the drought got any worse, the sediment might start flowing upstream from the beaches to the mountains. Confused staff members would neither support nor refute the new theory, but several of Norm's graduate students are reportedly working out the details.

Staff members ponder map of Sawpit Canyon watershed geology. From left to right: Brent Taylor, Bill Brown, Jessie Maniatis, Bill Brownlie and Ed Fall.

USGS Will Publish Project Maps

The U.S. Geological Survey, a sponsor of the Sediment Management Project, will publish several of the maps prepared as part of this project and also some project reports. Current plans call for the preparation of a number of map/reports suitable for inclusion in the Survey's Hydrologic Atlas Series. This series is devoted primarily to graphical presentation of a wide variety of hydrologic or geohydrologic data.

The typical map/report envisioned for the project atlas will consist of two map sheets that portray the study area at a scale of 1:250,000. Each sheet will be 86 by 107 centimeters. Sheet 1 will show the area from Point Conception eastward to a north-south line running through Santa Monica, and will contain an inset of the Tijuana River Basin in Mexico. Sheet 2 will show the remainder of the study area. Open space on each sheet will be used for explanatory text and related graphics.

Many of the intended products from the Sediment Management Project are suitable for publication in map format, and whereas many of these projects are also of interest to the USGS, we feel that the Hydrologic Atlas Series is an ideal way to publish some of our study results.

(continued from page 8)

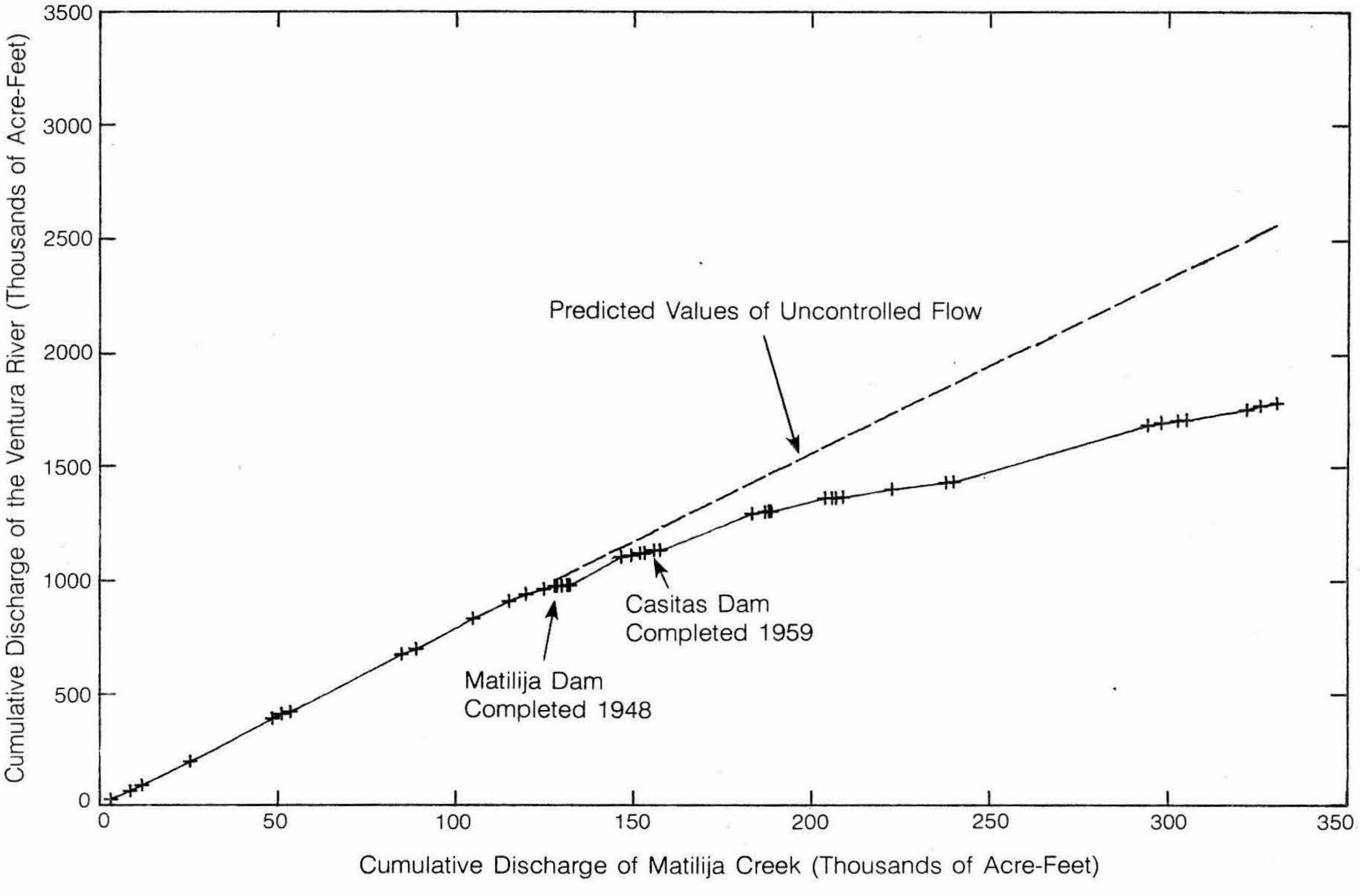
exception. However, the correlation between annual suspended sediment yield and annual runoff is quite high. On a logarithmic scale, the correlation coefficient is 0.99, with the sediment data ranging over three orders of magnitude. The relationship is non-linear in such a way that doubling the annual runoff would approximately triple the annual suspended sediment yield.

Combining the double mass analysis with the sediment rating relationship concludes the sediment modeling procedure. With the completion of Matilija Dam in 1949, the total runoff from the Ventura River, between 1948 and 1958, was reduced by 26% with a corresponding 21% reduction of total sediment yield. In 1959, Casitas Dam was completed and the total runoff for the years 1959 to 1975 was reduced a total of 53%, with a probable sediment yield reduction of 66% for that period. As the study progresses, our analysis will be further refined to produce estimates of absolute quantities of fine and coarse sediment deliveries.

Similar studies are currently underway on the other major rivers in the study area. However, due to the large variation in the data base and artificial river controls, the strategies used on these other rivers may differ from that used on the Ventura River.

Bill Brownlie is a doctoral student in civil engineering at Caltech. Dave Sarokin is a research assistant with the Environmental Quality Laboratory.

Double Mass Analysis — Ventura River Basin



Sponsors

As of June 1977, the following organizations have become sponsors of the Sediment Management Project:

Ford Foundation (through a discretionary grant to the Environmental Quality Laboratory which provided startup funding)
Los Angeles County Flood Control District
U.S. Geological Survey, Department of the Interior
Orange County Environmental Management Agency
Corps of Engineers, U.S. Army, Department of Defense

Future support is under consideration by:

San Diego County Department of Sanitation and Flood Control
Ventura County Flood Control District
Resources Agency, State of California
Sea Grant Program, Department of Commerce

We again gratefully acknowledge the interest and support given by these organizations.

Geologist Rattled

Geologist Ed Fall had a striking initiation into the Sediment Management Project. While climbing a Forest Service checkdam on his first field trip as a member of the staff, Ed accidentally grabbed hold of an unsuspecting rattlesnake. The somewhat shaken geologist survived the encounter uninjured. The snake was unavailable for comment.

New additions to the EQL staff: Wade Wells, John Perea and Jessie Maniatis. John assists Wade with his work for the Forest Service. Jessie recently joined EQL.

Project Staff Grows

In an effort to keep our readers informed of the composition of our staff at Caltech and Scripps, we would like to report the following changes:

At Scripps:
David Aubrey, a fourth-year doctoral student in physical oceanography has joined the Shore Processes Laboratory group to assist in compiling and analyzing beach profile data for the Sediment Management Project. David earned his B.S. degrees in Civil Engineering and Geology at USC before coming to Scripps.

At the Environmental Quality Laboratory:
Wade Wells, a hydrologist with the U.S. Forest Service Research Work Unit at Glendora, has joined our staff part-time to participate in watershed erosion process studies. Wade recently earned his Masters Degree in Forest Hydrology from the University of Arizona at Tucson.

Jessie Maniatis joined our staff as a research assistant in May to replace Suzanne Sayer, who left EQL to continue graduate studies. Jessie is a professional geologist with a B.S. and M.S. in Geology from Vanderbilt University. She worked as a research assistant at Harvard University before joining Caltech.

Dr. Harvey Kelsey, a geomorphologist who recently earned his doctorate at UC, Santa Cruz, will come to EQL this summer as a postdoctoral fellow. After completing undergraduate work at Princeton (Geology), Dr. Kelsey became interested in surface process geomorphology. His doctoral thesis involved a quantitative study of erosion processes and stream mechanics on the Van Duzen River basin in northern California.

Lloyd Townley has come to Caltech from Australia to do graduate work in hydraulics beginning this fall. His background is in civil engineering and he will work on the Sediment Management Project this summer and part-time during the school year.

Ed Fall, a Caltech doctoral student in geology, will work with EQL on the geomorphological classification and mapping of watersheds in the study area. Ed received his B.S. in geology from UCLA and has done field research with the USGS.

Non-Profit Org.
U.S. Postage
PAID
Pasadena, Calif.
Permit No. 583

Southern California Sediment Management Newsletter

California Institute of Technology
Environmental Quality Laboratory, 314-40
Pasadena, California 91125

Calendar of Events

During June and July, Dr. John F. Kennedy, Director of the Iowa Institute of Hydraulic Research at the University of Iowa, is a visiting associate at the Environmental Quality Laboratory. Dr. Kennedy is well known for his work on sediment transport by streams and by waves on beaches.

On August 9th, Bill Brown and Brent Taylor will make a special presentation before the Southern California Association of Engineering Geologists. The meeting is tentatively scheduled to be held at the Velvet Turtle Restaurant, 708 N. Hill Street, Chinatown, Los Angeles, and will commence with a social hour at 6:00 p.m. For details, contact Don Fife of the California Division of Mines and Geology (213) 620-3560. This will be an open meeting and public attendance is encouraged.

October 16–21 there will be an ASCE conference on Reservoir Sedimentation at the Hyatt Regency Hotel in San Francisco. Technical papers will be presented at this conference by J. Dan Davis of the Los Angeles Flood Control District, and Bill Brown and Brent Taylor. Dr. Norman Brooks, Director of EQL, will participate in a panel discussion entitled, "The River Environment." Dr. Brooks will discuss water, sediment, and related environmental problems, with an emphasis on coastal areas.

On October 27, Bill Brown will make a presentation on the Sediment Management Project at the Biennial Conference of the California District, Water Resources Division, USGS, at *Asilomar on the* Monterey Peninsula. This meeting will be attended by about 400 people from local, state, and federal agencies concerned with water in California.

Editor's Note

Southern California
SEDIMENT MANAGEMENT
NEWSLETTER

Editor: David Sarokin
Graphics: Margi Schulz Design

The Southern California Sediment Management Newsletter is published periodically by the Environmental Quality Laboratory to report on the Sediment Management Project and other developments in regional sediment management.

Printed on 100% recycled paper.

APPENDIX C

Preliminary Report on Coastal Sediment Delivery by the Santa Clara River, 1928-1975

by

William R. Brownlie

INTRODUCTION

For more than thirty years the Santa Clara River has been the primary natural contributor of sedimentary material to the shoreline in southern California. However, available data indicate that since 1956 annual deliveries of sand-sized material by this river have been reduced by about 37% or 15 million metric tonnes due to man-made upstream control structures. The Lower River Diversion Dam built in 1929, and Santa Felicia Dam built in 1956 on Piru Creek are the structures whose operations have been primarily responsible for this reduced shoreline sediment delivery.

This report outlines analysis procedures utilized in the study of the Santa Clara, and presents specific results regarding the natural hydrology (streamflow and sediment discharge) of the river, and artificial hydrology i.e. with the influence of man-made controls, from 1928-75.

DRAINAGE BASIN DESCRIPTION

The Santa Clara River Basin is the third largest of nine major drainage basins in southern California, with an area of 4,219 km^2. Currently, the drainage from 36.5% of this area is affected by four water-supply dams. In addition, streamflow to the ocean is affected by the Lower River Diversion Dam near the mouth.

The Santa Clara River (shown in figure 1) drains the transverse ranges in the northern portions of Los Angeles and Ventura Counties. The source of the river is Soledad Canyon in north central Los Angeles

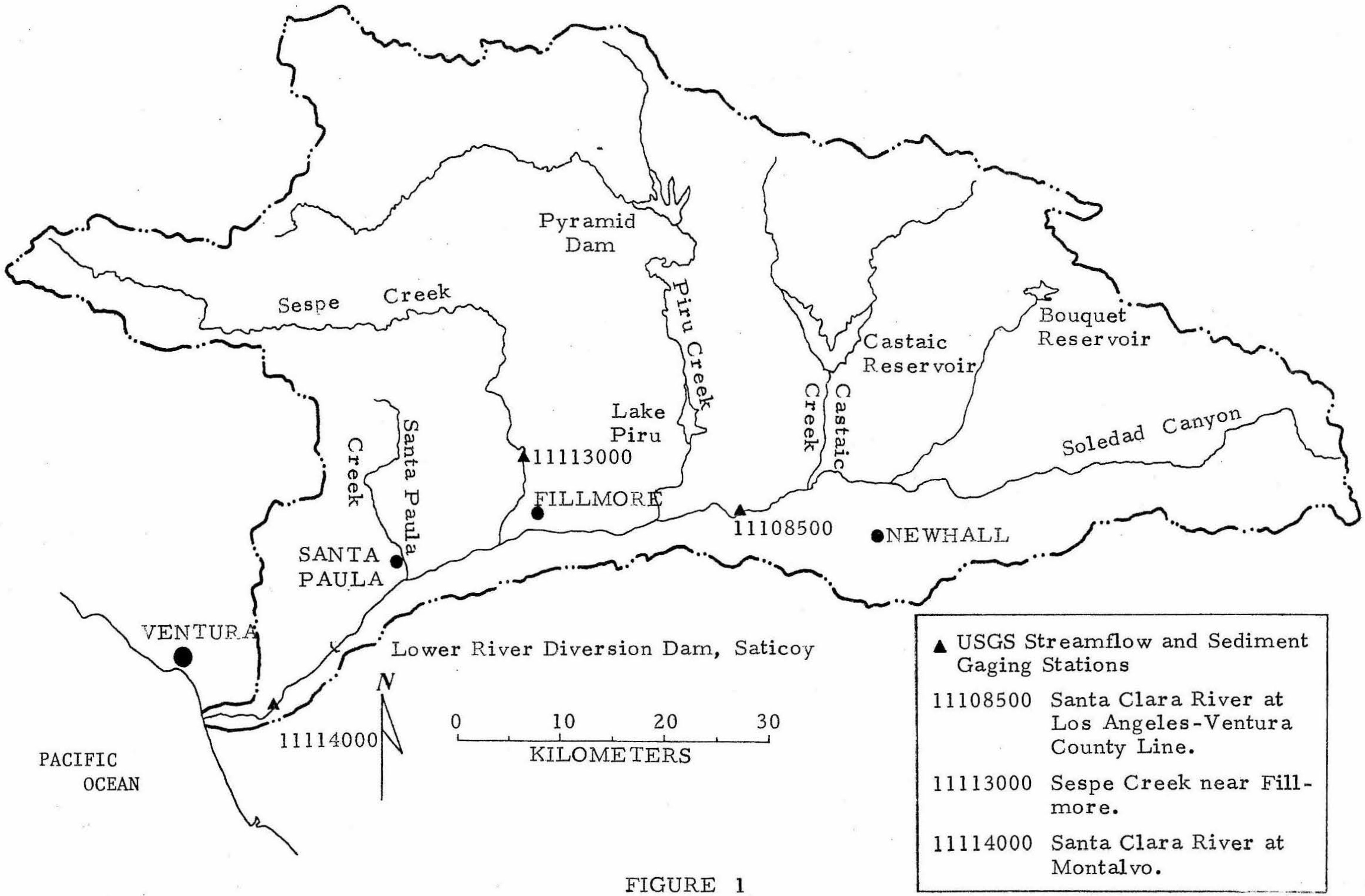


FIGURE 1

Santa Clara River Basin.

County. The mouth of the river is approximately 110 km and just southwest from the source, 4 km south of the City of Ventura. There are four principal tributaries; in downstream order, Castaic, Piru, Sespe, and Santa Paula Creeks, all of which enter from the north. Of these, only Sespe and Santa Paula Creeks are uncontrolled, except for small diversions. Watershed elevations range from sea level to more than 2000 m, at Alamo Mountain near Piru Creek. The lower 50 kilometers of the river flow over a broad and sandy alluvial plain that is dry most of the year. The median grain diameter of the river bed material along this reach is about 1 mm. The gaging station nearest to the ocean is at Montalvo, 7 kilometers inland from the coast. This station intercepts coastal runoff from more than 99% of the river basin's drainage area.

CONTROL STRUCTURES

The five major streamflow control structures on the Santa Clara River Basin are described in table 1 and shown in figure 1. A discussion of their influence on the annual water discharge at Montalvo follows.

Lower River Diversion Dam at Saticoy

Diversions at Saticoy have gradually increased since the dam's original construction in the 1929 water year. For example, for the years 1929 to 1938, the average annual diversion was 13.9×10^6 m^3 representing about 9% of the natural flow while for the years 1966 to 1975, the average annual diversion was 79.0×10^6 m^3, or 26% of the projected natural flow at Montalvo. Records of annual diversions have been kept since the inception of the facility by the United Water Conservation District in Santa Paula, California.

Bouquet Dam

Bouquet Dam, in the north-eastern corner of the watershed, is used primarily for storage of imported water. It controls less than 1% of the total drainage area and its influence on the annual streamflow at Montalvo has been considered negligible in the context of this report.

Santa Felicia Dam

Records of the United Water Conservation District (UWCD) indicate that with the exception of the 1969 water year, all inflow to Lake Piru has been prevented from reaching Montalvo. During the floods of January and February 1969, the capacity of the facility was exceeded and about 115,000 acre-feet of water spilled. During the water years 1956 to 1971, careful estimates were made of the yield of Santa Felicia Dam, i.e. the amount of water that would have flowed to the ocean under natural conditions. These estimates obtained by UWCD were determined by calculating percolation rates for individual storms and applying these rates to the inflow to Lake Piru. The sixteen year average indicates that 50.3% of the average annual inflow of 43,450 acre-feet would have reached the Pacific Ocean without reservoir operation.

Pyramid Dam

This facility is upstream from Lake Piru and effects no additional drainage area. It was constructed as part of the California Water Project which imports water from northern California. As of 1975, it had not affected streamflow at Montalvo.

Castaic Dam

Water retention during construction of this facility began in November 1970, and full operation began in June 1972. Castaic Reservoir was also constructed as part of the California Water Project.

TABLE 1

Control Structures

Structure	Water Year of Initial Operation	Capacity m^3 (in millions)	Drainage Area Upstream* (km^2)
Lower River Diversion Dam at Saticoy, California	1929	---	4131
Bouquet Dam	1934	45.0	35
Santa Felicia Dam	1955	134.9	1101
Pyramid Dam	1971	214.0	759**
Castaic Dam	1972	431.7	404

*Total drainage area of the Santa Clara River Basin = 4219 km^2.

**This area is also controlled by Santa Felicia Dam.

Current operating policy calls for releases from the reservoir which equal local natural inflows. However, the distribution of daily releases has been somewhat different than the distribution of daily inflows. Consequently, the annual flow at Montalvo has been influenced. So far, this influence has been quite small, as will be shown later in the report.

NATURAL AND ACTUAL STREAMFLOW AT MONTALVO

A timetable of streamflow data records on the Santa Clara River Basin is presented in table 2. The major obstacle in evaluating natural versus actual streamflow at Montalvo has been the fact that no data were collected at this station during the years 1933 through 1950. The procedure used to overcome this problem is outlined in table 3, and described below.

Step 1: Construction of Natural Flows

In this step the effects of Santa Felicia Dam and Castaic Dam are considered.

Santa Felicia Dam

The yield from this facility represents water which has been used primarily for groundwater recharge and irrigation, rather than being allowed to flow to the ocean. Therefore, the yield can be added directly to the flow at Montalvo and the diversion at Saticoy to estimate the natural flow. However, a portion of the annual release from the dam is channeled through the Saticoy diversion and therefore has already been considered and consequently must be subtracted from the above summation. The necessary data for this correction are available from the United Water Conservation District for the years 1956 through 1971.

There are two problems in estimating the effect of Santa Felicia Dam for 1972 through 1975. First, Pyramid Dam, upstream from Lake Piru, affects the distribution of inflows to Lake Piru, thereby making

TABLE 2

Timetable for Streamflow Records

<table>
<tr><th>Water Years / Location</th><th>1928</th><th>1929-32</th><th>1933-44</th><th>1945-55</th><th>1950-55</th><th>1956-1970</th><th>1971</th><th>1972-75</th></tr>
<tr><td>Santa Clara River at Montalvo</td><td colspan="2">USGS* Data available</td><td colspan="2">No data collected</td><td colspan="4">USGS data available</td></tr>
<tr><td>Saticoy Diversion</td><td></td><td colspan="7">Diversions begin, 1929, UWCD** records available</td></tr>
<tr><td>Castaic Creek</td><td colspan="3">No data collected</td><td colspan="3">USGS data available</td><td colspan="2">Castaic Reservoir DWR*** data available</td></tr>
<tr><td>Piru Creek</td><td colspan="5">USGS data available</td><td colspan="2">Santa Felicia Dam UWCD data available</td><td>USGS Data available</td></tr>
<tr><td>Sespe Creek</td><td colspan="8">Complete USGS record available including diversion to the Fillmore Irrigation Company.</td></tr>
<tr><td>Santa Paula Creek</td><td colspan="8">USGS data available, records of diversions to the Santa Paula Water Works not available for all years.</td></tr>
</table>

*United States Geological Survey

**United Water Conservation District, Santa Paula, California

***Department of Water Resources, Los Angeles California yield calculations difficult, since they must be calculated on a storm-by-storm basis. Second, no record was kept of the distribution of releases for this period. To estimate the yields for this period, a factor of .503 was applied to the corrected inflow to Lake Piru, where the factor is the ratio of average yeild to average inflow for 1956-71. The corrected inflow is calculated as 1.1425 times the flow on Piru Creek above Lake Piru (USGS station 1109600). This factor, determined by the UWCD, is based on the larger drainage area at the dam and the slightly higher mean annual precipitation over the larger area. On the average, for 1956-71, 29.8% of the annual yield passed through the diversion at Saticoy, this figure was applied to the yield for 1972-1975 to estimate the diverted portion of the release.

Castaic Dam

To examine the influence of this dam, mean daily inflows were compared with mean daily releases. These flows were then reduced to account for percolation between Castaic Reservoir and Saticoy. The percolation rates used, calculated by the UWCD, are given in table 4. These rates were plotted on a continuous curve, figure 2, relating the fraction of the original flow remaining at Saticoy as a function of mean daily flow at Castaic Reservoir. According to these calculations Castaic Dam seems to have had very little effect in reducing the annual flow at Montalvo. For example, releases of large amounts of water on February 11 and 13 of 1973 actually caused an increase of the actual annual flow over the probable flow without Castaic Dam for the 1973 water year.

It should be noted that percolation losses between Saticoy and Montalvo, 9 kilometers downstream, have been assumed to be on the order of local inflows and have therefore not been considered.

The annual data discussed in this section is given in table A of appendix 1. In this table Piru Yields refers to water yields to the basin due to Santa Felicia Dam. On the other hand, Castaic Yields refers to yields to the ocean from upstream of Castaic Reservoir.

TABLE 3

Procedural Outline for Construction of
Natural and Actual Annual Flows at Montalvo, 1928-1975

1. Construct natural flows for the periods 1928-1932 and 1950-1975 by combining actual flows with diversions at Saticoy and adding additional flows due to the effects of Santa Felicia Dam (1956-1975) and Castaic Reservoir (1971-1975).

2. Correlate constructed natural flows with tributary flows to reconstruct the natural flows at Montalvo for the period 1933-1950.

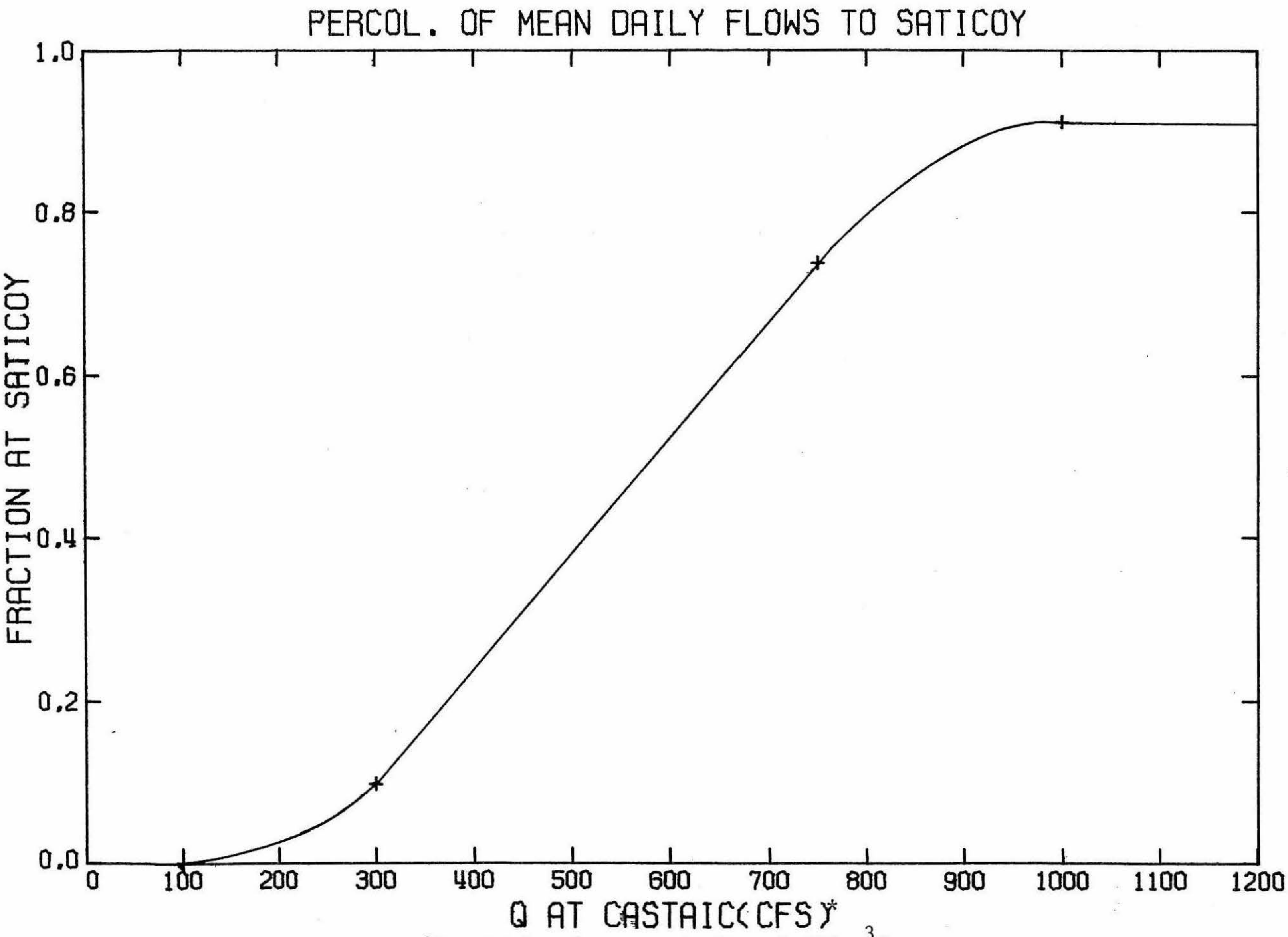
3. Actual flows for 1933-1950 are then equal to the natural flows minus the diversions at Saticoy for that period.

TABLE 4

Estimated Percolation Rates
between Castaic Reservoir and Saticoy*

Mean Daily Flow m^3/sec	Percolation Rate (%/km)	
	Upper 44.9 km	Lower 18.3 km
0 to 2.83**	> 1.8	> 1.25
2.83 to 14.2	1.57	1.09
14.2 to 28.3	0.456	0.317
> 28.3	0.155	0.106

*Data supplied by the United Water Conservation District.
**100 cfs



*Conversion factor: 1 cfs = 0.028 m^3/sec

FIGURE 2

Percolation losses between Castaic Reservoir and Saticoy as fraction of mean daily Castaic flow remaining at Saticoy vs. mean daily flow at Castaic (data supplied by the United Water Conservation District, Santa Paula, California.)

Summarizing, the natural flow has been calculated from the following equation:

Natural flow = Actual Flow + Diversion at Saticoy
+ Yield to Basin from Lake Piru
- Lake Piru Releases Diverted at Saticoy
+ Natural Yield to Ocean from Castaic Reservoir
- Actual Yield to Ocean from Castaic Reservoir. (1)

Step 2: Reconstructing Missing Data

To reconstruct flows at Montalvo for the years 1933-50 a correlation between flows at Montalvo and the combined flows of Piru Creek at Santa Felicia Dam and Sespe Creek near Fillmore (USGS station 11113000, including Fillmore Irrigation Company's canal) for the years 1928-32, 1951-71 was used. Several other single and multiple regression correlations were tested, including flow in Santa Paula Creek but all others yielded lower correlation coefficients.

The Piru Creek record had to be constructed from two records. USGS Station 11110000, slightly below Lake Piru was used for the years 1928-55. This record was multiplied by a factor of .9725 to account for the smaller drainage area at Santa Felicia Dam. For the period 1956-71 the inflow to Lake Piru was used, as calculated by the UWCD from monthly change in storage and evaporation.

The final regression equation which was used is given by:

$$\hat{M} = 0.104\ SP^{1.2} - 2847 \qquad (2)$$

Where M is the predicted annual flow at Montalvo, and SP is the combined annual flows of Sespe and Piru Creeks, in acre-feet. The correlation coefficient between M and $SP^{1.2}$ is 0.996. The equation and data are plotted in figure 3.

Step 3: Final Prediction

Having estimated the natural flow at Montalvo for 1933-50, the actual flow can be obtained by subtracting the diversion at Saticoy. The final estimates of natural flow are given in table 5, along with the prediction of natural flow from equation 2.

Sediment Predictions

To predict annual suspended sediment yield, a correlation with streamflow was obtained using annual discharge at Montalvo as the input variable. The best-fit equation, which gives zero sediment yield for zero discharge is given by:

$$\hat{Q}_S = 0.05177\mathrm{V}^{1.50375} \tag{3}$$

where $\hat{Q}_S$ is the predicted annual suspended sediment yield in metric tonnes, and V is the annual water discharge in acre-feet. The correlation coefficient between Q_S and $\mathrm{V}^{1.50375}$ on an arithmetic scale is 0.999. The data are plotted in figure 4, and replotted on a log scale in figure 5. Unfortunately, sediment data are only available for the period 1968-75, which somewhat limits confidence in the regression equation.

Sediment predictions from equation 3 are given in table 6, and cumulative values are given in table 7. The cumulative sediment estimates in table 7 are plotted in figure 6. The estimates indicate that during the years 1928 through 1955, man had a minor influence on the suspended sediment delivery to the ocean, reducing it by only 6%. Whereas with the introduction of Santa Felicia Dam, the suspended sediment yield was reduced by about 37% for the period 1956 through 1975.

SUMMARY AND CONCLUSIONS

Man's first major influence on the streamflow and sediment transport in the lower Santa Clara River came in 1929 with the construction of the Lower River Diversion Dam at Saticoy. During the 27 year period from 1929 through 1955 the estimated natural (without controls) average annual streamflow to the coast of 164.0×10^6 m^3/year was reduced by

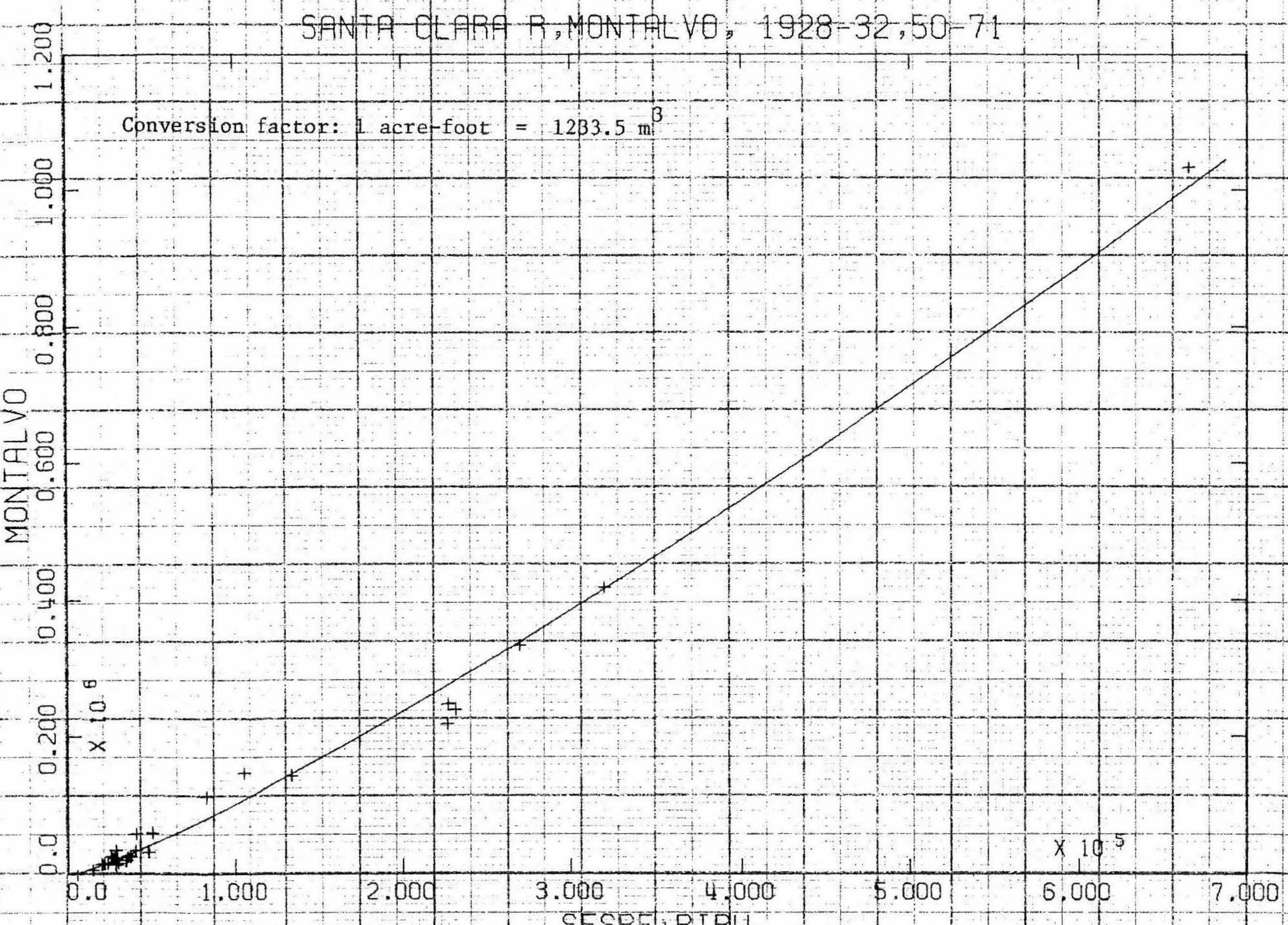


FIGURE 3

Correlation of annual flow at Montalvo with combined natural annual flows on Sespe Creek at Fillmore and Piru Creek at Santa Felicia Dam, in acre-feet.

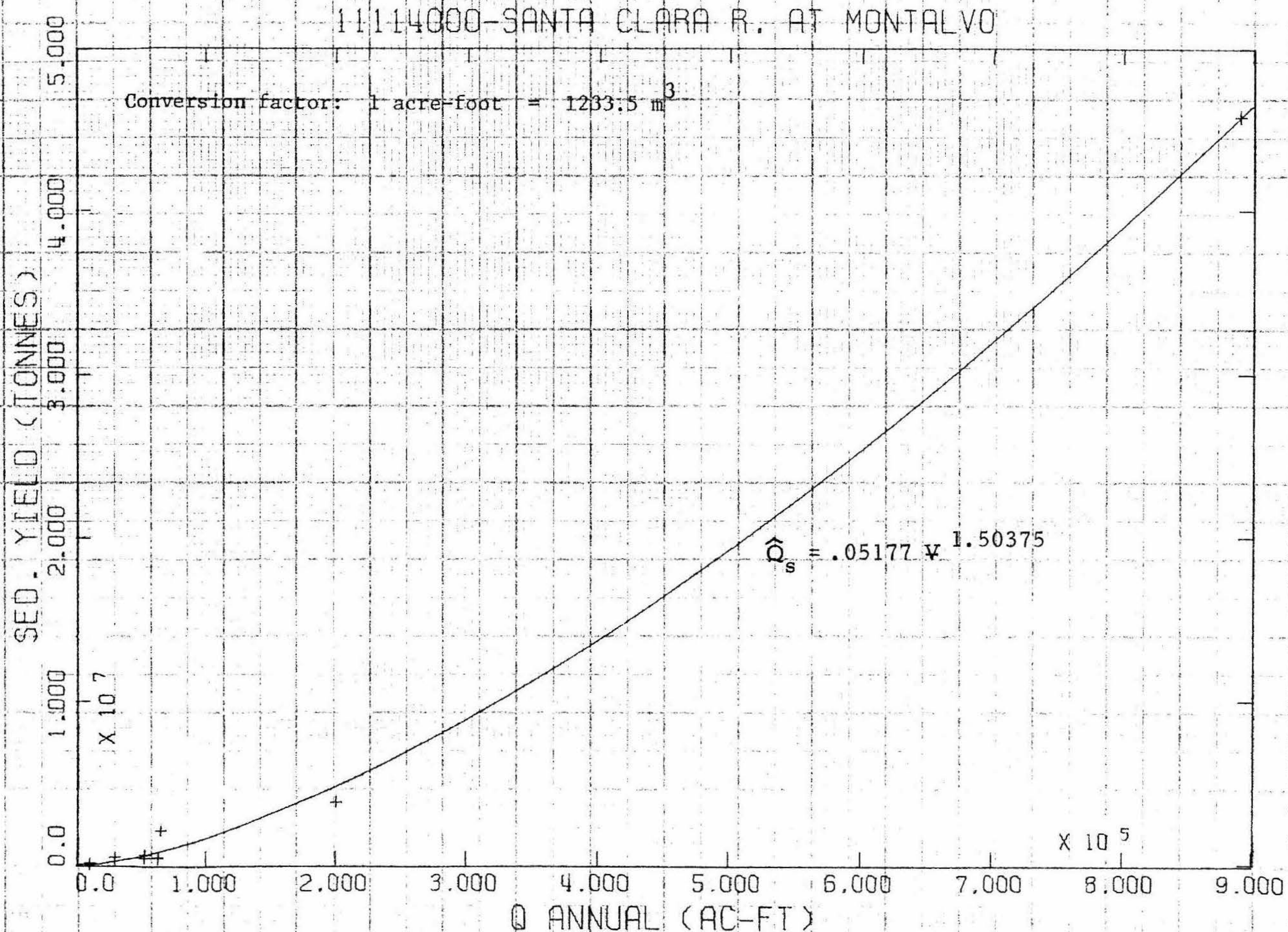


FIGURE 4

Annual sediment yield in tonnes vs. annual discharge in acre-feet for the Santa Clara River at Montalvo (USGS station 11114000).

Table 5

NATURAL AND ACTUAL FLOW, AT MONTALVO, IN ACRE-FEET...NOTE, E-ESTIMATED.*
(Conversion factor: 1 acre-foot = 1233.5 m^3)

YEAR	ACTUAL	NATURAL	BEST FIT
1928	15700.	15700.	21544.
1929	29400.	34080.	20166.
1930	15500.	22920.	18859.
1931	15800.	22970.	20858.
1932	133000.	142596.	145101.
1933	24246.E	34276.E	34276.
1934	54931.E	62891.E	62891.
1935	102849.E	121662.E	121662.
1936	47870.E	60778.E	60778.
1937	271472.E	291609.E	291609.
1938	472139.E	485841.E	485841.
1939	66724.E	80269.E	80269.
1940	26974.E	43764.E	43764.
1941	878806.E	879202.E	879202.
1942	68823.E	68823.E	68823.
1943	340188.E	340188.E	340188.
1944	328695.E	330651.E	330651.
1945	81178.E	85916.E	85916.
1946	78451.E	95693.E	95693.
1947	45358.E	68116.E	68116.
1948	-518.E	7287.E	7287.
1949	2191.E	7725.E	7725.
1950	5450.	15146.	15820.
1951	0.	0.	598.
1952	192000.	217367.	274198.
1953	3310.	25160.	27292.
1954	12370.	32296.	40446.
1955	945.	12996.	20239.
1956	14190.	33959.	32348.
1957	5620.	19196.	26382.
1958	278500.	418359.	415901.
1959	19320.	59530.	42868.
1960	331.	14038.	12545.
1961	459.	5954.	7968.
1962	224500.	333781.	338073.
1963	6220.	25594.	17790.
1964	4720.	14906.	13921.
1965	7590.	25049.	28959.
1966	154100.	246557.	274872.
1967	114200.	238392.	281450.
1968	9780.	58049.	32691.
1969	889500.	1033121.	1004560.
1970	52140.	112345.	79946.
1971	66690.	147091.	108023.
1972	29710.	68194.	46490.
1973	200800.	283541.	260814.
1974	62610.	133885.	80936.
1975	52300.	121537.	96806.

* Estimated values based on best fit values in column 4, from regression analysis of natural flows.

FIGURE 5

Same as Figure 4,
plotted on a logarithmic scale

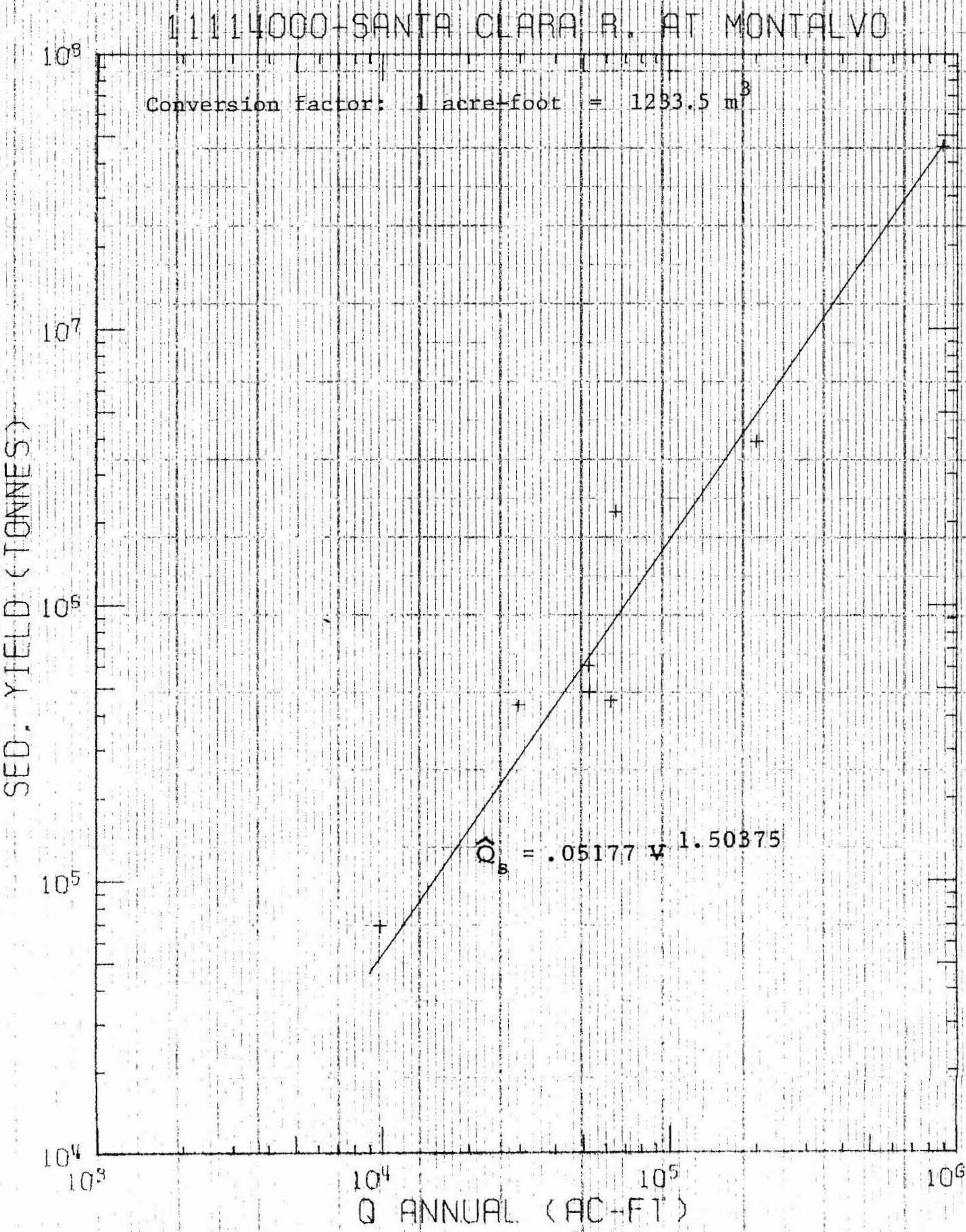


Table 6

PG 1 OF 1

PREDICTED ACTUAL AND UNCONTROLLED SEDIMENT DISCHARGE, AT MONTALVO IN TONNES.

(Conversion factor: 1 acre-foot = 1233.5 m^3)

YEAR	ACTUAL Q ANNUAL*	NATURAL Q ANNUAL*	ACTUAL SED.YLD.	NATURAL SED.YLD.
1928	15700.	15700.	105597.	105597.
1929	29400.	34080.	271235.	338700.
1930	15500.	22920.	103581.	186527.
1931	15800.	22970.	106610.	187139.
1932	133000.	142596.	2624544.	2914430.
1933	24246.	34276.	202988.	341633.
1934	54931.	62891.	694332.	851025.
1935	102849.	121662.	1783024.	2295429.
1936	47870.	60778.	564557.	808395.
1937	271472.	291609.	7674049.	8545881.
1938	472189.	485841.	17640736.	18413296.
1939	66724.	80269.	930201.	1228224.
1940	26974.	43764.	238288.	493341.
1941	878806.	879202.	44894192.	44925040.
1942	68823.	68823.	974560.	974560.
1943	340188.	340188.	10774197.	10774197.
1944	328695.	330651.	10231514.	10323254.
1945	81178.	85916.	1249203.	1360432.
1946	78451.	95693.	1186626.	1599780.
1947	45358.	68116.	520603.	959538.
1948	-518.	7287.	625.	33295.
1949	2191.	7725.	5465.	36349.
1950	5450.	15146.	21512.	100044.
1951	0.	0.	0.	0.
1952	192000.	217367.	4558533.	5493776.
1953	3310.	25160.	10163.	214604.
1954	12370.	32296.	73785.	312393.
1955	945.	12996.	1543.	79471.
1956	14190.	33959.	90701.	336893.
1957	5620.	19196.	22529.	142872.
1958	278500.	418359.	7974758.	14705023.
1959	19320.	59530.	144262.	783559.
1960	331.	14038.	319.	89244.
1961	459.	5954.	521.	24572.
1962	224500.	333781.	5767100.	10470473.
1963	6220.	25594.	26241.	220195.
1964	4720.	14906.	17328.	97670.
1965	7590.	25049.	35398.	213182.
1966	154100.	246557.	3275082.	6639816.
1967	114200.	238392.	2087048.	6312019.
1968	9780.	58049.	51825.	754439.
1969	889500.	1033121.	45718224.	57258704.
1970	52140.	112345.	641966.	2036277.
1971	66690.	147091.	929492.	3053690.
1972	29710.	68194.	275547.	961195.
1973	200800.	283541.	4876360.	8192825.
1974	62610.	133885.	845318.	2650867.
1975	52300.	121437.	644932.	2289064.

* In acre-feet.

Table 7

CUMULATIVE ACTUAL AND UNCONTROLLED SEDIMENT DISCHARGE, AT MONTALVO IN TONNES.

(Conversion factor: 1 acre-foot =1233.5 m^3)

YEAR	ACTUAL Q ANNUAL*	NATURAL Q ANNUAL*	ACTUAL SED.YLD.	NATURAL SED.YLD.
1928	15700.	15700.	105597.	105597.
1929	45100.	49780.	376833.	444297.
1930	60600.	72700.	480414.	630824.
1931	76400.	95670.	587024.	817963.
1932	209400.	238266.	3211567.	3732392.
1933	233646.	272542.	3414556.	4074025.
1934	288577.	335433.	4108888.	4925050.
1935	391426.	457095.	5891912.	7220479.
1936	439296.	517873.	6456469.	8028874.
1937	710768.	809482.	14130518.	16574755.
1938	1182957.	1295323.	31771248.	34988048.
1939	1249681.	1375592.	32701440.	36216272.
1940	1276655.	1419356.	32939728.	36709616.
1941	2155461.	2298558.	77833920.	81634656.
1942	2224284.	2367381.	78808480.	82609200.
1943	2564472.	2707569.	89582688.	93383408.
1944	2893167.	3038220.	99814192.	103706656.
1945	2974345.	3124136.	101063408.	105067088.
1946	3052796.	3219829.	102250032.	106666864.
1947	3098154.	3287945.	102770624.	107626416.
1948	3097636.	3295232.	102771248.	107659696.
1949	3099827.	3302957.	102776720.	107696048.
1950	3105277.	3318103.	102798224.	107796096.
1951	3105277.	3318103.	102798224.	107796096.
1952	3297277.	3535470.	107356768.	113289872.
1953	3300587.	3560630.	107366928.	113504480.
1954	3312957.	3592926.	107440720.	113816864.
1955	3313902.	3605922.	107442256.	113896336.
1956	3328092.	3639881.	107532960.	114233232.
1957	3333712.	3659077.	107555488.	114376112.
1958	3612212.	4077436.	115530240.	129081136.
1959	3631532.	4136966.	115674512.	129864688.
1960	3631863.	4151004.	115674816.	129953936.
1961	3632322.	4156958.	115675344.	129978496.
1962	3856822.	4490739.	121442448.	140448976.
1963	3863042.	4516333.	121468688.	140669168.
1964	3867762.	4531239.	121486016.	140766848.
1965	3875352.	4556288.	121521408.	140980016.
1966	4029452.	4802845.	124796496.	147619840.
1967	4143652.	5041237.	126883536.	153931856.
1968	4153432.	5099286.	126935360.	154686304.
1969	5042932.	6132407.	172653584.	211945008.
1970	5095072.	6244752.	173295552.	213981280.
1971	5161762.	6391843.	174225056.	217034960.
1972	5191472.	6460037.	174500592.	217996160.
1973	5392272.	6743578.	179376960.	226188992.
1974	5454882.	6877463.	180222272.	228839856.
1975	5507182.	6998900.	180867200.	231128912.

* In acre-feet.

about 8% with a corresponding 6% reduction of the predicted natural suspended sediment discharge of 4.2 million tonnes/year. In 1956, the introduction of Santa Felicia Dam reduced the effective drainage area of the basin by 26%. This factor, combined with increased diversions at Saticoy further reduced the streamflow to the ocean for the 20 year period, 1956 through 1975. During this period the estimated natural average annual streamflow of 209.3×10^6 m^3/year was reduced by 35% with a 37% reduction of the predicted natural average annual suspended sediment yield of 5.9 million tonnes per year.

Table 7 would indicate that the total reduction in suspended sediment transport to the coast from 1928 to 1975 has been on the order of 50 million tonnes. Grain-size analysis of suspended sediment samples collected at Montalvo indicates that about 15% of the suspended load is sand. Furthermore, an estimate of bedload transport by the USGS for the 1975 water year, a not untypical year, indicates that approximately 15% as much material is transported as bed load discharge (unmeasured) as is transported in suspension (measured). Combining these two figures, a ballpark estimate of the total reduction in sand transport to the coast during this period (1928-75) can be made as 30% of the suspended load, for a total of 15 million tonnes. Assuming a density of 1.6 tonnes per cubic meter (100 lbs/ft^3) this would represent 9.4 million cubic meters, or a 94 kilometer section of beach, 100 meters wide and one meter deep.

ACKNOWLEDGEMENTS

All data relating to Santa Felicia Dam were supplied by the United Water Conservation District, Santa Paula, California, with the cooperation of Richard Farnsworth. All data regarding Castaic Reservoir operations and flow records were supplied by the California Department of Water Resources, Southern District, with the cooperation of Frank Meccia. Sediment data and other streamflow data were published by the United States Geological Survey as Water Resources Data for California.

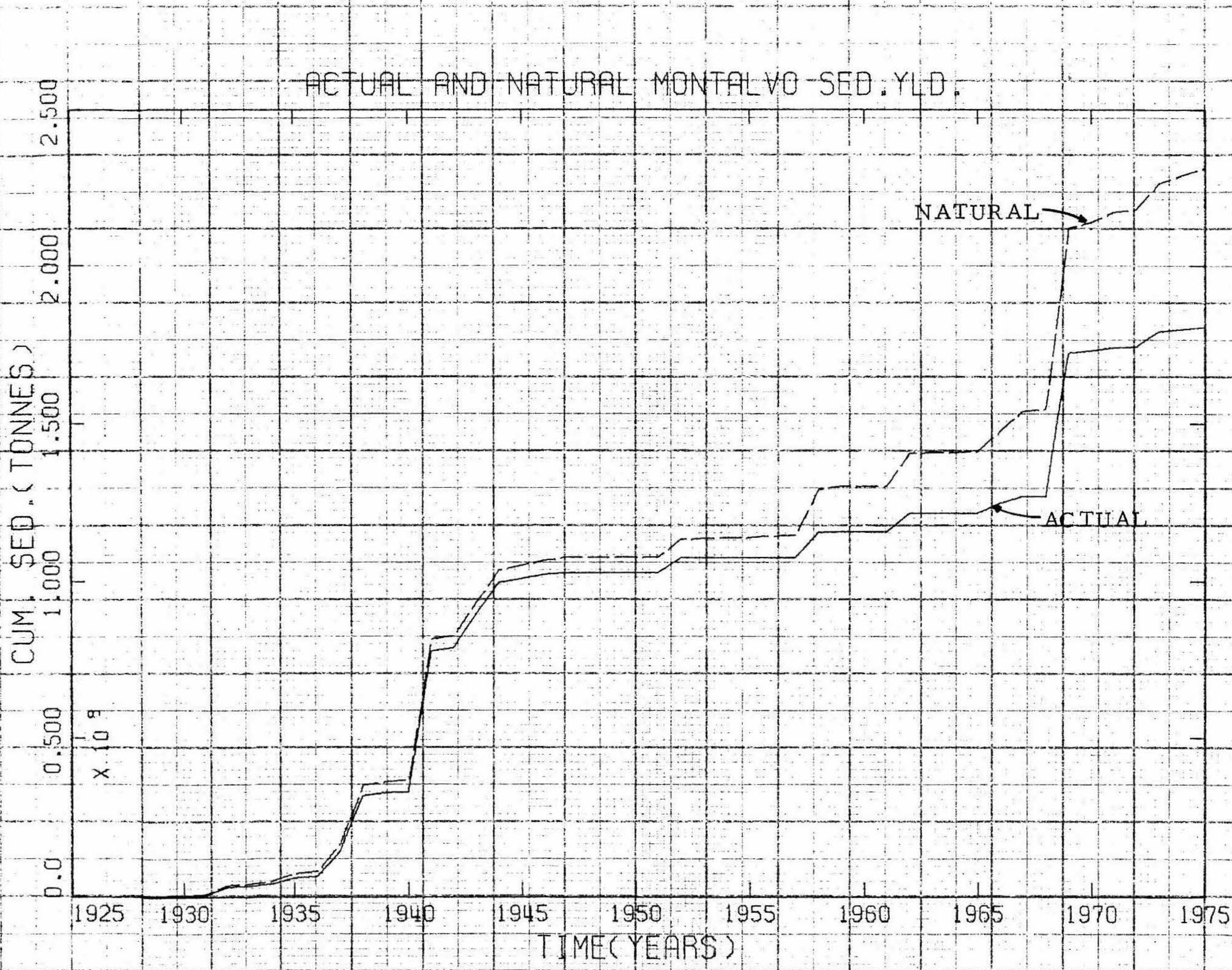


FIGURE 6

Cumulative sediment yield of the Santa Clara River at Montalvo, in tonnes, under actual and natural conditions.

APPENDIX 1

Annual Flow Data

Table A

SANTA CLARA RIVER SYSTEM, ANNUAL FLOWS IN ACRE-FEET.*

WATER YEAR	L.PIRU YIELD	DIVERTED YIELD **	CASTAIC NAT.YLD.	CASTAIC ACT.YLD.
1928	0.	0.	0.	0.
1929	0.	0.	0.	0.
1930	0.	0.	0.	0.
1931	0.	0.	0.	0.
1932	0.	0.	0.	0.
1933	0.	0.	0.	0.
1934	0.	0.	0.	0.
1935	0.	0.	0.	0.
1936	0.	0.	0.	0.
1937	0.	0.	0.	0.
1938	0.	0.	0.	0.
1939	0.	0.	0.	0.
1940	0.	0.	0.	0.
1941	0.	0.	0.	0.
1942	0.	0.	0.	0.
1943	0.	0.	0.	0.
1944	0.	0.	0.	0.
1945	0.	0.	0.	0.
1946	0.	0.	0.	0.
1947	0.	0.	0.	0.
1948	0.	0.	0.	0.
1949	0.	0.	0.	0.
1950	0.	0.	0.	0.
1951	0.	0.	0.	0.
1952	0.	0.	0.	0.
1953	0.	0.	0.	0.
1954	0.	0.	0.	0.
1955	0.	0.	0.	0.
1956	2610.	0.	0.	0.
1957	500.	0.	0.	0.
1958	78780.	13510.	0.	0.
1959	7130.	3100.	0.	0.
1960	0.	560.	0.	0.
1961	0.	0.	0.	0.
1962	68120.	7410.	0.	0.
1963	1040.	4040.	0.	0.
1964	560.	1220.	0.	0.
1965	1230.	0.	0.	0.
1966	43590.	4880.	0.	0.
1967	45090.	11170.	0.	0.
1968	2600.	0.	0.	0.
1969	71990.	23780.	0.	0.
1970	9660.	28200.	0.	0.
1971	16730.	4540.	3713.	0.
1972	12051.	3591.	20.	0.
1973	28297.	8433.	3430.	4180.
1974	14781.	4405.	596.	283.
1975	15820.	4714.	60.	0.

* Conversion factor: 1 acre-foot - 1233.5 m^3

** Portion of Lake Piru yield diverted at Saticoy.

Table B

SANTA CLARA RIVER SYSTEM, ANNUAL FLOWS IN ACRE-FEET. *

WATER YEAR	SESPE CREEK	L.PIRU OUTFLOW	L.PIRU INFLOW	PIRU CR. NAT.FLOW	ST.PAULA CREEK
1928	19500.	0.	0.	10454.	3500.
1929	18900.	0.	0.	9637.	3680.
1930	18000.	0.	0.	9180.	3150.
1931	16900.	0.	0.	12351.	3590.
1932	83000.	0.	0.	51542.	19900.
1933	32200.	0.	0.	10308.	7490.
1934	52000.	0.	0.	16435.	11300.
1935	83600.	0.	0.	32929.	12840.
1936	52730.	0.	0.	13868.	13450.
1937	171000.	0.	0.	67754.	31910.
1938	239000.	0.	0.	125161.	44320.
1939	46050.	0.	0.	37159.	8460.
1940	32500.	0.	0.	18886.	5300.
1941	375600.	0.	0.	220077.	57680.
1942	42240.	0.	0.	31305.	6890.
1943	170500.	0.	0.	100654.	39740.
1944	143100.	0.	0.	121757.	22430.
1945	54460.	0.	0.	33435.	12180.
1946	64450.	0.	0.	31441.	11190.
1947	45340.	0.	0.	27600.	7310.
1948	7960.	0.	0.	6448.	1720.
1949	9070.	0.	0.	5854.	1960.
1950	16900.	0.	0.	7070.	3490.
1951	3520.	0.	0.	2344.	993.
1952	150200.	0.	0.	76730.	30880.
1953	22330.	0.	0.	13401.	4350.
1954	33090.	0.	0.	15229.	5870.
1955	17060.	0.	0.	11553.	3010.
1956	29600.	8100.	10850.	11060.	5260.
1957	23780.	11590.	9610.	11050.	3530.
1958	226200.	73490.	97590.	93980.	47080.
1959	31880.	29940.	15670.	18700.	5600.
1960	12890.	10870.	5380.	7520.	2130.
1961	8940.	7240.	4100.	6270.	1260.
1962	179000.	63000.	82980.	90760.	26210.
1963	16530.	20670.	7580.	9530.	3340.
1964	13660.	13430.	5880.	8260.	3030.
1965	26440.	10300.	9420.	10930.	4670.
1966	157700.	60910.	69060.	69690.	28460.
1967	157100.	60400.	62550.	74770.	37430.
1968	24290.	14180.	14740.	16700.	7880.
1969	465300.	161100.	212800.	200140.	112700.
1970	56150.	58610.	23300.	26790.	7780.
1971	66780.	40070.	37080.	39010.	12800.
1972	29920.	30690.	20970.	23958.	4500.
1973	161500.	48750.	49240.	56257.	35240.
1974	54380.	35360.	25720.	29385.	11560.
1975	65340.	22400.	27530.	31453.	11510.

* Conversion factor: 1 acre-foot = 1233.5 m^3

Table C

SANTA CLARA RIVER SYSTEM, ANNUAL FLOWS IN ACRE-FEET. *

WATER YEAR	MONTALVO ACT.FLOW**	SATICOY DIVERS'N
1928	15700.	0.
1929	29400.	4680.
1930	15500.	7420.
1931	15800.	7170.
1932	133000.	9596.
1933	24246.	10030.
1934	54931.	7960.
1935	102849.	18813.
1936	47870.	12908.
1937	271472.	20137.
1938	472189.	13652.
1939	66724.	13545.
1940	26974.	16790.
1941	878806.	396.
1942	68823.	0.
1943	340188.	0.
1944	328695.	1956.
1945	81178.	4738.
1946	78451.	17242.
1947	45358.	22758.
1948	-518.	7805.
1949	2191.	5534.
1950	5450.	9696.
1951	0.	0.
1952	192000.	25367.
1953	3310.	21850.
1954	12370.	19926.
1955	945.	12051.
1956	14190.	17159.
1957	5620.	13076.
1958	278500.	74589.
1959	19320.	36180.
1960	331.	14267.
1961	459.	5495.
1962	224500.	48571.
1963	6220.	22374.
1964	4720.	10846.
1965	7590.	16229.
1966	154100.	53747.
1967	114200.	90272.
1968	9780.	45669.
1969	889500.	95411.
1970	52140.	78745.
1971	66690.	64498.
1972	29710.	30004.
1973	200800.	63627.
1974	62610.	60586.
1975	52300.	58071.

* Conversion factor: 1 acre-foot = 1233.5 m^3

** 1933 through 1950 estimated from regression analysis.

RECENT EROSION IN THE SAN GABRIEL MOUNTAINS

by

William M. Brown III[1] and Brent D. Taylor[2]

INTRODUCTION

In 1975 a regional sediment management study was initiated as a joint project of the Environmental Quality Laboratory, California Institute of Technology, and the Shore Processes Laboratory, Scripps Institution of Oceanography. One of the primary objectives in this study is to quantitatively define the natural regional sediment budget and the specific effects man-made controls have had on this budget. General factors in the regional budget are diagramed schematically in Figure 1. It is the intent of this study to quantify the individual regional factors, e.g. annual sediment delivery to the shoreline by the Santa Clara River, and define the natural dynamic equilibrium of this system. As a part of the study, an analysis is being made of geologic, topographic, climatic, vegetative, and other factors that determine the production of sedimentary debris and consequent reservoir sedimentation in coastal Southern California.

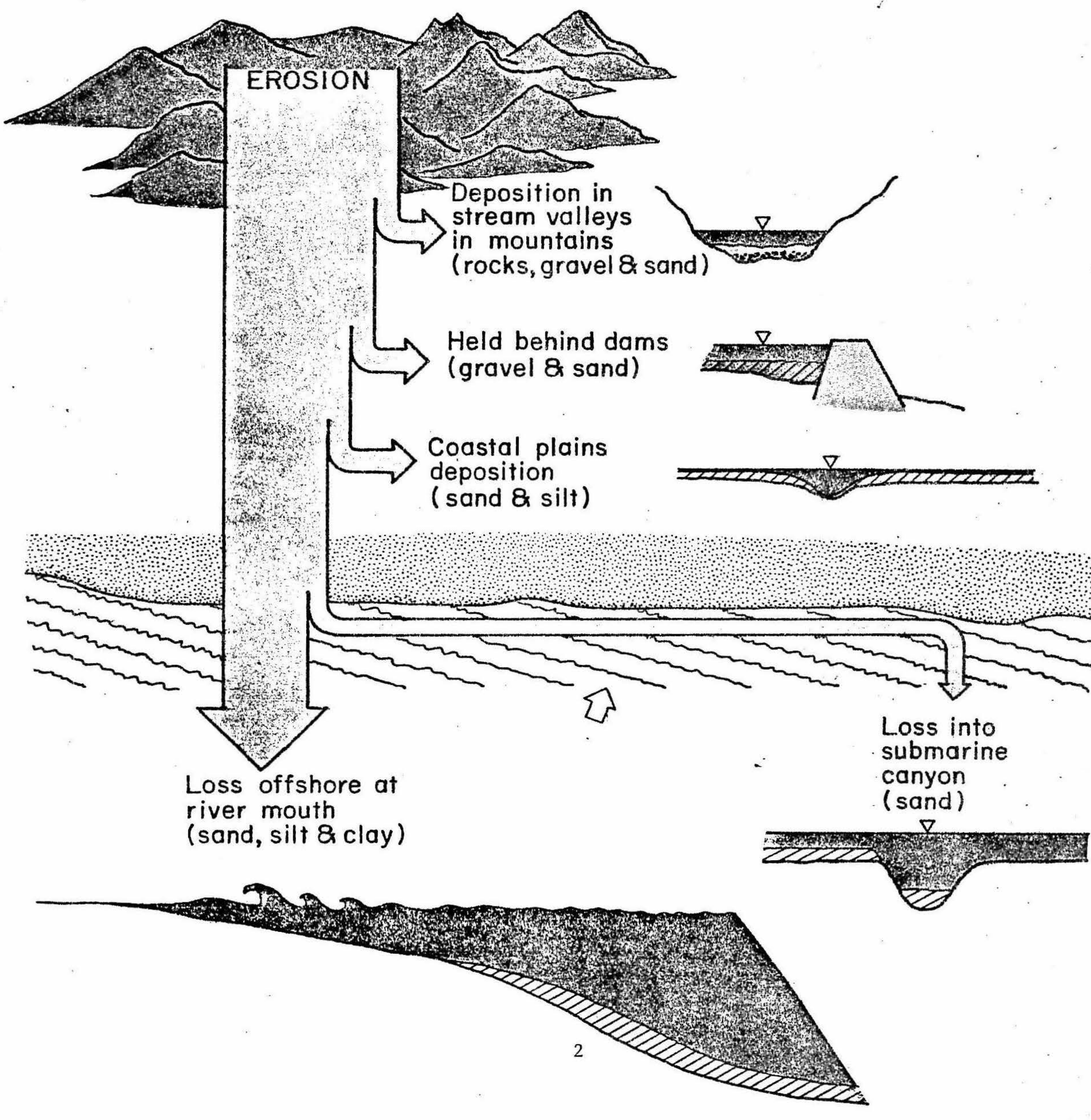
---

[1]Hydrologist, U.S. Geological Survey, California Institute of Technology, Pasadena, California.

[2]Associate Member, ASCE; Senior Research Engineer, Environmental Quality Laboratory, California Institute of Technology, Pasadena, California.

Figure 1

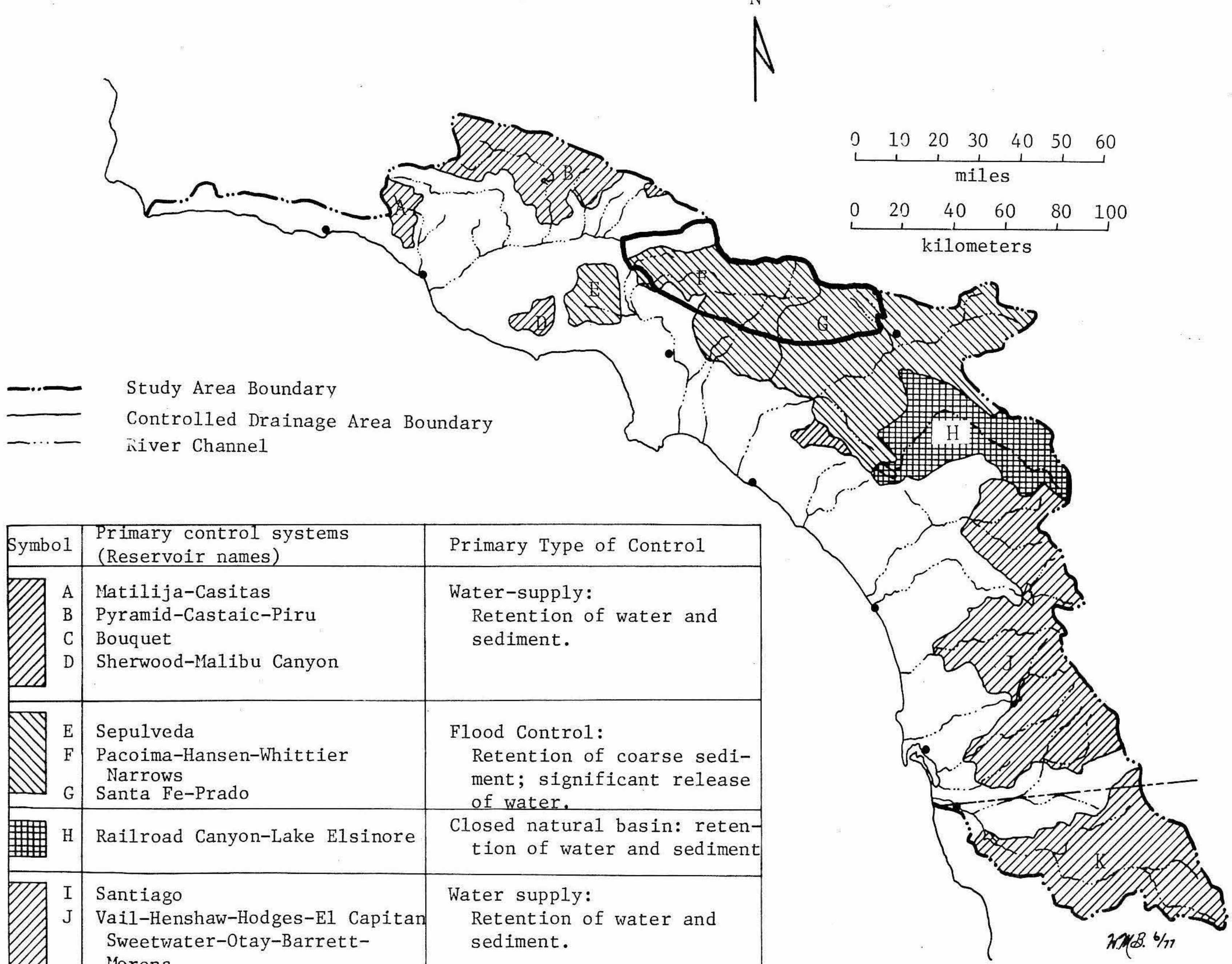
Schematic Diagram of Sediment Budget Factors
in Southern California



PHYSICAL SETTING

The Sediment Management Project study area (Figure 2) is bounded by the Pacific Ocean and the drainage divide of coastal streams between Point Conception and the U.S.A.-Mexico border. These boundaries enclose some 33,100 km^2 of varied inland terrain including broad, flat-lying plains and high rugged mountains. Altitudes range from mean sea level to more than 3500 meters and abrupt changes in topography are characteristic of the region. The region is noted for its mild semi-arid climate (and consequent deficiencies in local water supply) but also severe flooding and upland erosion during brief, intense winter storms. Runoff from these storms typically combines with crushed, broken, and decomposed rocks on steep hillslopes and in high-gradient stream channels to form viscous slurries that can carry massive boulders onto the adjoining alluvial fans and flood plains.

The study area is populated by approximately 12.5 million people, most of whom live on the coastal plains. Accomodation of the large human population in this area has led to the construction of an extensive system of flood control, debris retention, and water-supply reservoirs that today exert significant controls on all major drainages in the region. These controls may either attenuate peak flows without altering the total annual water discharge or store the inflow of water for subsequent diversion, thereby reducing the annual volume of flow to the mouth of the drainage basin. The retention of sediment with either type of reservoir control is significant, and in most cases the downstream availability and transport of sediment is reduced.



Symbol	Primary control systems (Reservoir names)	Primary Type of Control
A B C D	Matilija-Casitas Pyramid-Castaic-Piru Bouquet Sherwood-Malibu Canyon	Water-supply: Retention of water and sediment.
E F G	Sepulveda Pacoima-Hansen-Whittier Narrows Santa Fe-Prado	Flood Control: Retention of coarse sediment; significant release of water.
H	Railroad Canyon-Lake Elsinore	Closed natural basin: retention of water and sediment
I J K	Santiago Vail-Henshaw-Hodges-El Capitan Sweetwater-Otay-Barrett-Morena Rodriguez	Water supply: Retention of water and sediment.

Figure 2

Sediment Management Project study area showing principal stream courses and drainage basins controlled by dams. San Gabriel Mountains are outlined in bold relief.

NUMBER, TYPE, AND DISTRIBUTION OF RESERVOIRS

There are approximately 300 major reservoirs and 500 minor reservoirs in the study area. The major reservoirs include flood-control and water-supply reservoirs, and debris basins. The minor reservoirs include primarily sediment check dams, and farm ponds.

Debris basins are structures intended to trap debris emanating from mountain canyons and permit relatively clear water to pass downstream (Los Angeles County Flood Control District, 1976, p. 232.) Approximately 150 of these structures are located along the southern faces of the Transverse Ranges and in local hills between Ventura and San Bernardino. Few debris basins exist elsewhere in the study area, and none have been built in the southern Peninsular Ranges (Figure 2).

Flood-control reservoirs are structures intended to trap sediment, attenuate flood peaks, retain water for percolation into the ground, and permit specified quantities of runoff to pass downstream. Five of these structures are located on major watercourses in the central part of the study area.

Water-supply reservoirs are primarily intended to store water, although flood control commonly is a secondary purpose of these structures. In the central part of the study area post-storm releases are made for ground water replenishment through percolation in flood-control reservoirs and channels downstream. Elsewhere, however, reservoirs are designed to trap all inflow, water and debris, without downstream releases except in cases of emergency. Several water-supply reservoirs throughout the study area are fed primarily by water imported from Northern California and the Colorado River. Approximately

150 water-supply reservoirs are located on major and minor watercourses throughout the study area.

The variety and degree of artificial controls on the movement of water and sediment pose problems in analyzing natural sedimentary processes. Nevertheless, the available data make it possible to estimate upland sediment yields, particularly for a well-defined geomorphic unit like the San Gabriel Mountains.

SAN GABRIEL MOUNTAINS: A CASE STUDY

The San Gabriel Mountains (Figure 2) can be considered a distinct geomorphic unit characterized by intensely faulted granitic-metamorphic rock. The terrain formed is steep, rugged, and heavily dissected by drainage channels. Relief of individual canyons ranges up to 900 meters, and many mountain peaks exceed 2000 meters in altitude. These mountains are characterized by recent tectonic uplift and severe hydraulic erosion which inhibit development of a stable soil layer. Thus, surficial material tends to be loose and rocky merging into parent rock at depths of less than one meter.

Below altitudes of about 1800 meters, the terrain is typically covered with chaparral, a plant community consisting of many species of shrubs adapted to shallow, rocky soils.

The steep, high San Gabriel Mountains pose an abrupt barrier to extra-Pacific, cyclonic storms that arrive in Southern California between October and May each year. The orographic effect of the mountain rise produces very intense precipitation that can exceed 50 cm in 24 hours. Average annual precipitation ranges from 50 cm along the base of the mountains to more than 100 cm near the summits. Except for the light moisture received from summer fog and occasional, scattered thunderstorms or tropical hurricanes, the mountains remain hot and dry from June through September.

During this dry period, the chaparral becomes highly vulnerable to burning. Many chaparral plants produce volatile oils on their leafy parts that invite burning. Thus, fires are a common occurrence in chaparral, and break out frequently in these mountains from both human and natural causes. This burning exposes the friable slopes to the direct impacts of rainfall and runoff until significant vegetal cover is reestablished three to five years later. Interestingly, as part of their ecological adaption chaparral plants also produce fire-resistant root systems and seeds which sprout within days following a fire.

RESERVOIR SEDIMENTATION DATA

Reservoir sedimentation data for 17 reservoirs in the San Gabriel Mountains are summarized in Table 1, and the reservoir locations and drainages are shown on Figure 3. These data were derived from numerous individual sedimentation surveys over a fifty-year period by the Los Angeles County Flood Control District (written communication, 1977). The debris production data were converted to longer-term erosion rates by dividing the total amount of sediment accumulation by the area of the drainage basin and the period of measurement. These rates express average

TABLE 1

Reservoir Statistics and Drainage Basin Erosion Rates Based on Sediment Accumulation in the Reservoirs

Reservoir Name[1] and Type		Map Location	Drainage Area (km^2)	Period of Record	Years	Average Erosion Rate (mm/yr)	% of Drainage Area Burned 1920-1975
Pacoima	WSFC	1	73.0	1929-73	44	1.07	60+
Big Tujunga	WSFC	2	213.2	1931-71	40	0.72	20+
Haines	DR	3	3.96	1935-75	40	1.04	150+
Dunsmuir	DR	4	2.18	1935-75	40	2.25	290+
West Ravine	DR	5	0.65	1935-75	40	4.09	100+
Devil's Gate	WSFC	6	82.6	1920-74	54	1.59	100+
Las Flores	DR	7	1.17	1935-75	40	3.04	195+
Sierra Madre	WSFC	8	6.19	1927-75	48	0.79	0+
Eaton Wash	WSFC	9	32.1	1937-72	35	1.24	130+
Santa Anita	WSFC	10	28.0	1927-73	46	1.97	120
Sawpit	WSFC	11	8.65	1927-70	43	1.93	125
Cogswell	WSFC	12	101.5	1934-69	35	1.23	50
San Gabriel	WSFC	13	423.5[2]	1939-71	32	1.46	85+
Big Dalton	WSFC	14	11.6	1929-72	43	1.31	130
San Dimas	WSFC	15	42.0	1922-71	49	0.87	150+
Live Oak	WSFC	16	6.48	1922-71	49	0.60	20+
Thompson Creek	WSFC	17	7.77	1928-69	41	0.76	120+

[1]WSFC = Water-supply and Flood control
DR = Debris retention

[2]Excludes drainage into Cogswell Reservoir.

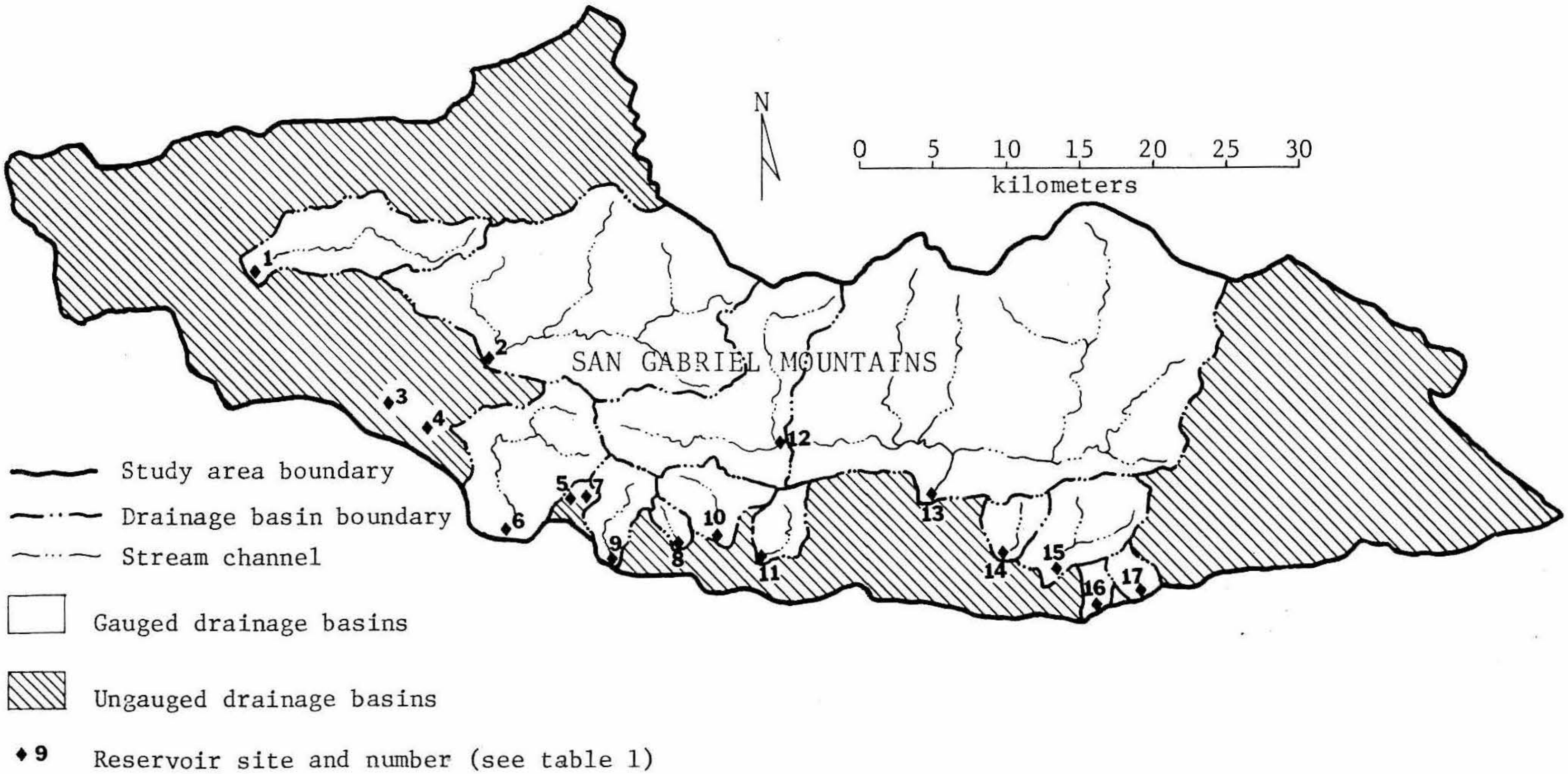


Figure 3

Coastal Drainage Basins and Reservoir Locations in the San Gabriel Mountains.

erosion as if denudation occurred evenly over the drainage basin. The computed erosion rates are plotted as a function of drainage basin area in Figure 4.

DISCUSSION

The variations in mean annual erosion rates in Table 1 and Figure 4 are due, in part, to differences in the periods of measurement among the 17 drainage basins. An aggregation of erosion rates based on different periods of measurement improves estimates of longer-term erosion rates by effectively enlarging the statistical sample of independent annual events. It also produces, however, spurious variations in computed erosion rates. Among the 17 watersheds listed in Table 1 mean annual watershed precipitation varies 10-20%. Since in this area there is a high correlation between mean annual precipitation and other precipitation parameters important in watershed erosion processes, this variation in mean annual precipitation produces some variation in basin erosion rates.

In addition, differences in topography, surficial geology and vegetative cover among the 17 drainage basins must also account for part of the variation in Figure 4.

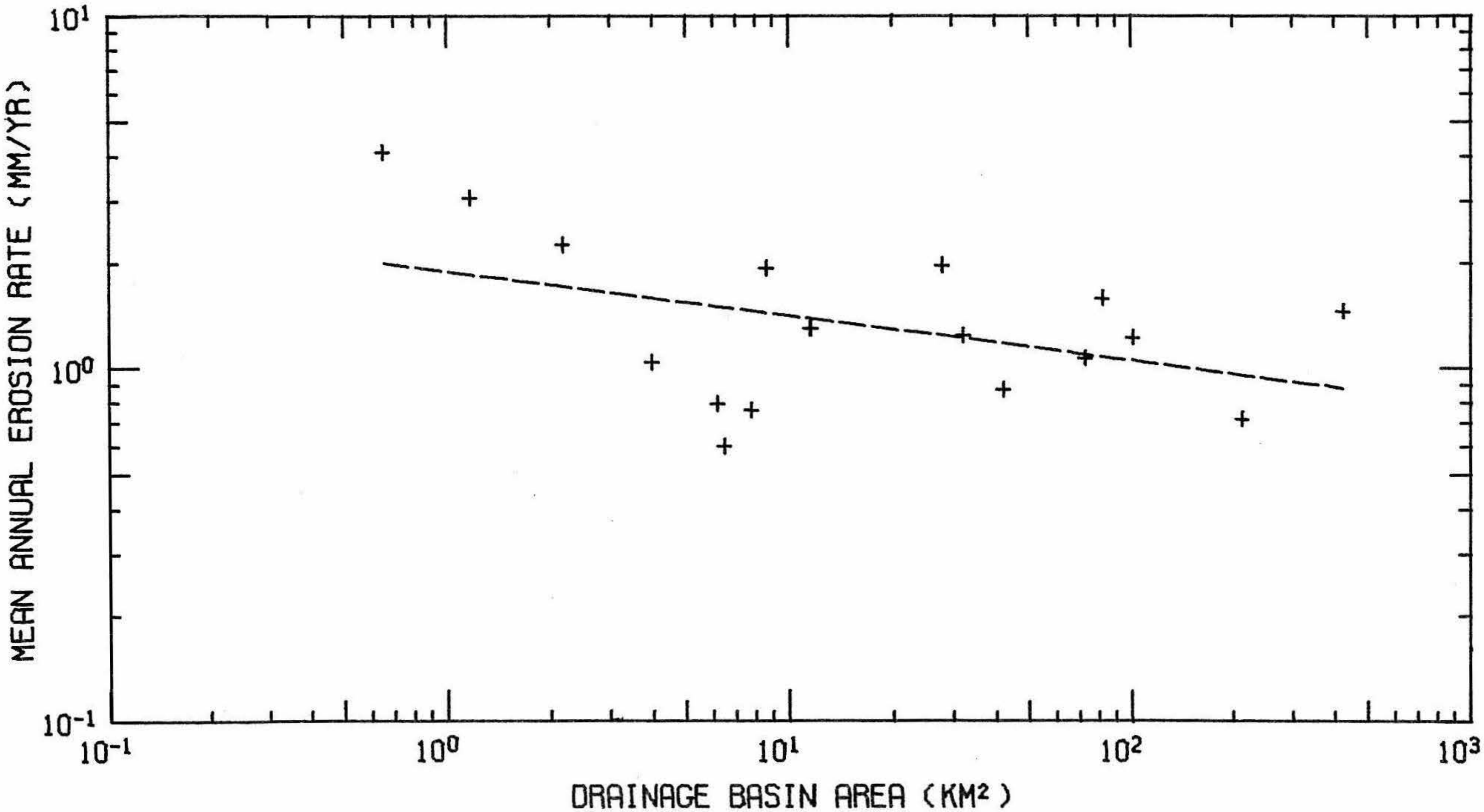


Figure 4

Annual Erosion Rates as a Function of Drainage Area for 17 Basins in the San Gabriel Mountains

However, specific differences and their quantitative relation to long-term erosion rates have not yet been determined.

Table 1 outlines the fire history for each of the watersheds from 1920 to 1975. These data indicate large differences in the frequency of burn on the 17 drainage basins. The severe effect of fire on sediment yield is exemplified by the response of Shields Canyon, a small drainage basin near Big Tujunga Canyon, to a fire in November of 1975. During 12 months following this fire with below normal precipitation Shields experienced an erosion rate of 30 mm. This is an order of magnitude higher than would have been expected from this small basin in an unburned condition.

The data plotted in Figure 4 suggests a slight reduction in erosion rate with increase in drainage basin area. This inverse relation has been observed by other investigators (Brune, 1948; Langbein and Schumm, 1958; Scott and Williams, 1974). Probable reasons given by Langbein and Schumm are that as drainage basin area increases, 1) mean basin slopes tend to be reduced suggesting a reduced overall erosion potential and a greater probability of internal deposition of eroded material, and 2) peak rainfall intensities during storms tend to become non-uniform and thus less erosive.

In Figure 4 a straight line has been fitted to the data by the least-squares technique. The slope of this line would suggest that erosion rates are proportional to drainage basin area raised to the -0.1 power, which is approximately the same as the specific relation identified by Brune. If it is assumed that the larger drainage basins in the San Gabriels are made up primarily of smaller basins with areas of approximately 1 km^2, the inverse straight-line relation would indicate that approximately 20% of the material eroded in a 10 km^2 basin is internally deposited and only 80% is lost from the watershed during a 30 to 50 year period. For a basin 100 km^2 in area the inverse relation suggests that some 40% of the sediment eroded from the subbasins would be internally deposited, and 60% delivered to the mouth of the watershed.

It may be assumed that for a larger drainage basin, internal deposition would take place primarily along the main channel rather than in the steeper tributaries. For a 100 km^2 drainage basin a main channel 10 km in length might be expected with a channel width near the mouth on the order of a 100 m. If is assumed that the width of the channel increases linearly with length from its upstream origin and at a given location remains relatively constant for changes in bed elevation, then a linearly varying mean annual aggradation in the main channel for a 40% internal deposition and a net mean annual basin erosion rate of 1 mm, would result in a 50-year aggradation at the mouth of some 10 m. Observed long-term channel aggradations in San Gabriel basins are significantly less than this, thus suggesting that the larger basins cannot be treated simply as a connected array of smaller basins. However, these results suggest that differences in relative internal deposition could be a significant factor in the observed variation in erosion rates for larger basins.

The combined areas of basins draining into reservoirs listed in Table 1 account for some 50% of the total area of the San Gabriel Mountains which drain to the coast, and the range of individual areas among these basins is representative. Therefore based on these data a reasonable estimate of sediment yield can be made for the entire geomorphic unit.

The San Gabriel Mountains rise abruptly from alluvial coastal plains and thus the line of demarcation between these two fundamental land forms is generally easy to define. This natural boundary might be thought of as the division between erosional and depositional surfaces. Based on the data in Figure 4, mean annual sediment yields have been estimated for each basin draining to this boundary. To obtain these estimates for drainage basins where longer-term sediment yield data are not available the straight-line relation in Figure 4 was used to compute the erosion rate. On basins where the control structure for sediment entrapment is located upstream from the erosional/depositional boundary, the longer-term erosion rate measured above the reservoir was corrected for the increase in basin area to the boundary using the inverse relation defined previously.

In Figure 5 cumulative sediment yield and cumulative basin area respectively, are plotted as functions of location along the erosional/depositional boundary. The coordinate locations are measured along the boundary from its western origin at the ridge where coastal drainage begins in the San Gabriel Mountains (see Figure 2).

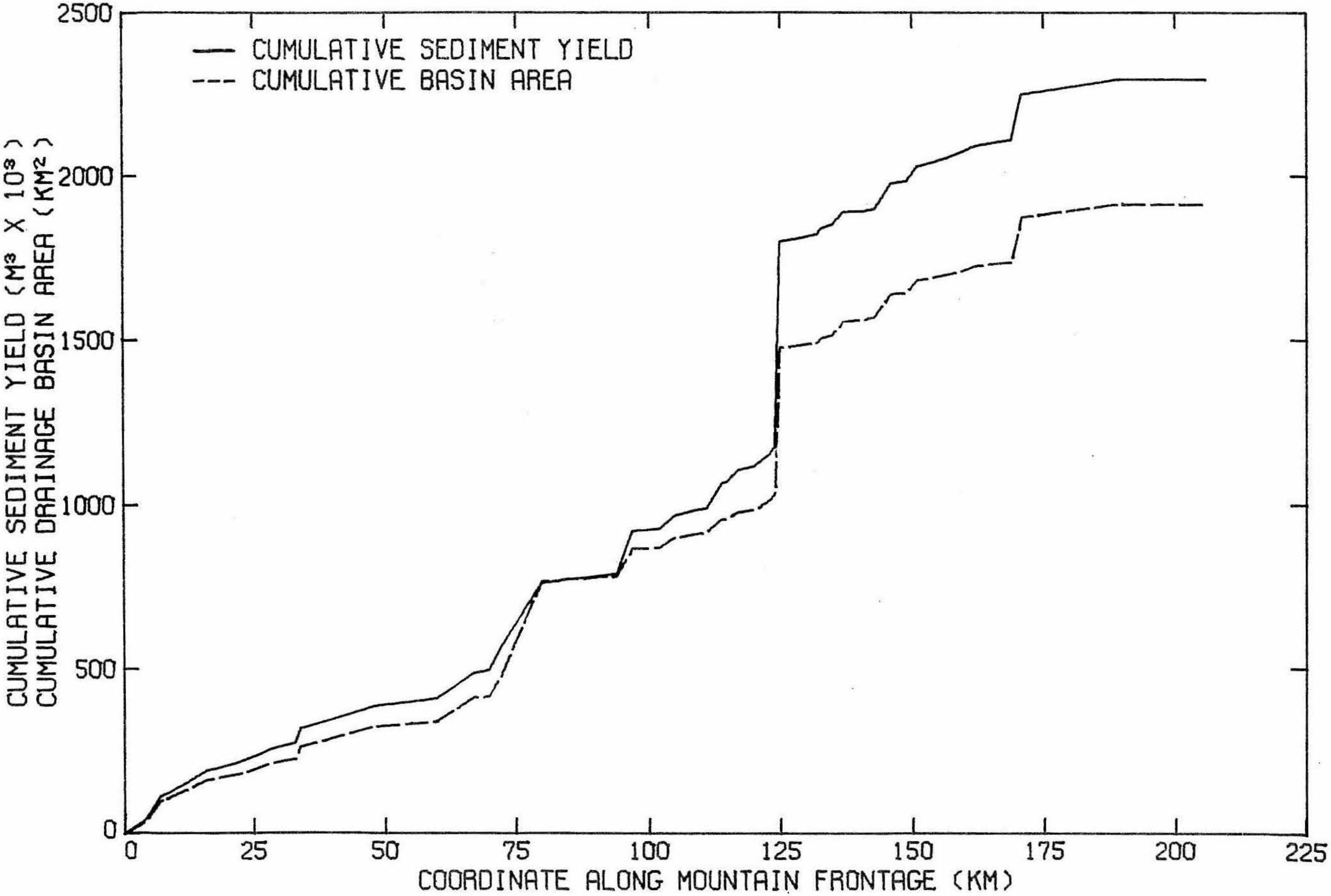


Figure 5

Cumulative Annual Sediment Yield and Cumulative Drainage Basin Area Along San Gabriel Mountain Frontage (Erosional/Depositional Boundary)

Figure 5 illustrates the primary relationship between basin area and sediment yield. Variations in erosion rate among the 17 gaged basins which include the largest basins, do not significantly affect this close relationship. Due to the large variation in basin areas, sediment yield along the boundary is non-uniform. Approximately two-thirds of the sediment flux takes place along the central third of the boundary. This would suggest that the rate of alluvial fan building along this section is some four times greater than for the two end sections.

Ironically, it is along this central section of the boundary that urbanization is greatest, and the heavy concentration of debris retention structures has virtually stopped natural deposition on alluvial fans. Whereas along the two end sections of the boundary some natural deposition still occurs. Thus man has qualitatively reversed the relative growth rates of alluvial fans along the boundary.

Data in Figure 5 indicates a longer-term mean erosion rate for the coastal drainage in the San Gabriel Mountains of 1.2 m/1000 years. Scott and Williams (1974) have estimated the mean uplift rates in these mountains to be at least 7.6 m/1000 years, more than six times the erosion rate. This would suggest a net growth rate of approximately 6 m/1000 years, or 0.4%/1000 years based on present mean relief.

Limited available data suggest that the general size distribution of the sediment yielded from the San Gabriel Mountains is 50% clay and silt-sized particles, 35% sand (0.06 mm to 2.0 mm) and 15% coarser material. Under natural conditions the coarser material is deposited at the mouths of the canyons on the alluvial fans, and the finest material is carried to the ocean and deposited in the deeper off-shore areas. It is the sand-sized material that nature uses to form and nourish beaches along the southern California shoreline. The above data suggest that the coastal drainage from the San Gabriel Mountains produces an average of 800,000 m^3/year of sand. This coupled with the fact that natural drainage from these mountains feeds four major rivers that drain to the ocean along a 150 km reach of the shoreline suggests that the San Gabriel Mountains are an important element in the natural sediment budget of the beaches in Southern California.

REFERENCES

Brune, G., Rates of sediment production in midwestern United States, Soil Conservation Service TP-65, 1948.

Langbein, W. B. and Schumm, S. A., Yield of sediment in relation to mean annual precipitation, Transactions, American Geophysical Union, Vol. 39, No. 6, December 1958, pp. 1076-1084.

Los Angeles County Flood Control District, Hydrologic Report: 1974-75, 1976.

Scott, K. M., and Williams, R. P., Erosion and sediment yields in mountain watersheds of the Transverse Ranges in Ventura and Los Angeles Counties, California--Analysis of rates and processes, Water-Resources Investigations 47-73, U. S. Geological Survey, June 1974.